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ABSTRACT

The links between population growth, resource use, and environmental quality are too complex to permit straightforward generalizations about causal relationships. However, rapid population growth has increased the number of poor people in developing countries, thus contributing to the degradation of the environment and the renewable resources of land, water, and nonhuman species on which humans depend. Demands of the rich industrial countries have also generated environmental pressures; the developed nations have been foremost in consumption of the nonrenewable resources of fossil fuels, metals, and nonmetallic minerals. On the other hand, population and economic growth have also stimulated technological and management changes that help supply and use resources more effectively. Wide variations in the possible ultimate size of world population and accelerating technological change make future interrelationships of population, resources, and the environment uncertain as well as complex. But those interrelationships are mediated largely by government policies. Responsible governments can bring about a sustainable balance in the population/resource/environment equation by adopting population and development policies that experience has shown could reduce future population numbers below the additional five billion projected by the United Nations for the close of the twenty-first century, coupled with proven management programs in both developing and developed countries that could brake and reverse the depletion and degradation of natural resources. Sixty-nine references and 12 tables are provided. (AEM)

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POPULATION BULLETIN
Vol. 42, No. 2, July 1987

Population, Resources, Environment: An Uncertain Future

By Robert Repetto

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Abstract—The links between population growth, resource use, and environmental quality are too complex to permit straightforward generalizations about direct causal relationships. However, rapid population growth has increased the number of poor people in developing countries, thus contributing to degradation of the environment and the renewable resources of land, water, and nonhuman species on which humans depend. Demands of the rich industrial countries have also generated environmental pressures and have been foremost in consumption of the socalled nonrenewable resources of fossil fuels, metals, and nonmetallic minerals. On the other hand, population and economic growth have also stimulated technological and management changes that help supply and use resources more effectively. Wide variations in the possible ultimate size of world population and accelerating technological change make future interrelationships of population, resources, and the environment uncertain as well as complex. But those interrelationships are mediated largely by government policies. Responsible governments can bring about a sustainable balance in the population/resource/environment equation by adopting population and development policies that experience has shown could reduce future population numbers in developing countries below the additional 5 billion indicated in current United Nations medium projections, coupled with proven management programs in both developing and developed countries that could brake and reverse the depletion and degradation of natural resources.

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Population, Resources, Environment: An Uncertain Future

By Robert Repetto

	Page
Introduction	3
Intellectual Background	4
The Population Prospect	9
Consequences of Population Expansion	11
Living standards	11
Poverty and inequalities	12
Effects on renewable resources	14
Effects on nonrenewable resources	23
Effects on environmental quality	26
Consequences of Future Population Growth	28
Adaptations to Population Growth	35
Room to Maneuver	38
References	41
Selected Bibliography	43

Figures

1. World, Developing and Developed Regions, Population Growth: 1750-2100	9
2. Species Resistant to Pesticides: 1940-1980	22
3. Total Resource Base	24
4. U.S. Relative Price Trends for Major Resources: 1870-1985	25
5. World Commercial Energy Consumption: 1974-1985	26
6. Atmospheric Concentrations of Environmentally Important Trace Gases: 1975-1985	28
7. Recent Long-Term Projections of World Primary Energy Consumption to 2050	29
8. Regional Oil Consumption and Reserves: 1985	30
9. U.S. Consumption of Major Materials: 1890-1985	32
10. U.S. Consumption of Minor Metals: 1900-1985	33

Tables

1. World, Developing and Developed Regions, Projected Population Growth: 1985-2100	11
2. Socioeconomic Indicators, Selected Countries: About 1960 and 1984	12
3. Distribution of Agricultural Holdings and Area, by Size of Holdings: 1980	14
4. Consumption of Major Resource Commodities, by Region: 1984	15
5. World Land Use, by Region: 1850-1980	16
6. World Increases in Crop Area and Yields, by Region: 1964-1985	21
7. World Reserves and Cumulative Production of Selected Minerals: 1950-1980	23
8. Projections of U.S. Metal Demand in 1985 Versus Actual Demand	31
9. Projected Growth Rates of U.S. Population, GNP, and Mineral Demands: 1971-2025	33
10. Potential Yields for Cereals in 90 Developing Countries, by Land Class	35
11. Operations and Technology Used in Tropical African Farming Systems	36
12. Scientists and Engineers Engaged in Research and Development, by Region: 1980	37

Box

1. Long-Term Agricultural and Land-Use Trends in India	18

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POPULATION BULLETIN

Vol. 42, No. 2, July 1987

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A dust storm in Kenya. Rapid population growth in developing countries and resource demands of rich developed countries have revived ancient concerns about the interactions of population, resources, and the environment. Though the future of these interactions is uncertain, government policies to stem population growth and strengthen resource management could help relieve further inevitable pressures on resources and the environment.

Population, Resources, Environment: An Uncertain Future

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Dr. Repetto wishes to thank James Joslin for able research assistance and Katherine Harrington for help in preparing the manuscript for this Bulletin.

Events of the past two decades have revived a vigorous debate about the connections between population pressures and resource scarcities. Many of the events that precipitated this debate were not directly demographic in origin: for example, oil price shocks and the rise and decline of the Organization of Petroleum Exporting Countries (OPEC) cartel, inflation and disinflation in the world economy, fluctuations in world weather and agricultural production, and changes in reigning political ideologies. However, such events have again called attention to basic questions about population and resource interactions. What are the economic and environmental consequences of rapid population growth in poor countries and of incipient population decline in rich countries? What are the limits that life on a finite planet impose on economic and demographic expansion and progress? What, if anything, should be a responsible government's response to promote the welfare of its current and future citizens?

This *Bulletin* attempts to show that there are no easy answers to these questions. Both with regard to the past and outlook for the future, the connections between population growth, resource use, and environmental quality are too complex to permit straightforward generalizations about direct causal relationships. Further, many of these connections are manifested only at the local level and may be missed when the perspective is regional or global, where much of the debate has focused.

Only the demographic record to date is clear. World population has doubled from 2.5 billion in 1950 to 5 billion in 1987, with over 85 percent of that growth occurring in developing countries. Rapid population growth coincided with efforts to raise living standards in developing countries and created pressures on the financial, physical, and human resources of those countries. These pressures have evidently exacerbated the problem of alleviating poverty in developing countries and thus have contributed to degradation of the environment and the renewable resources of land, water, and nonhuman species on which humans depend. However, the demands of rich industrial countries have also often led to environmental stress and have been foremost in drawing upon the world's so-called nonrenewable resources: fossil fuels, metals, and nonmetallic minerals. On the other hand, population and economic growth have also stimulated tech-

nological and organizational innovations that show that resources can be supplied and used more effectively.

The future interaction of population expansion and resource use is uncertain. The United Nations currently estimates that although the rate of growth has slowed, world population numbers could double again to reach just over 10 billion before stabilizing late in the next century, with all but a small fraction of that increase again coming in developing countries. Such long-range projections are speculative, however, and the actual ultimate size of world population could vary substantially, depending on social, economic, and political conditions. Similarly, in a world of accelerating technological change, future resource demands and supplies cannot be predicted with confidence even ten years ahead.

Despite this uncertainty about future trends in population growth and in resource supplies and demand and the complexity of their interrelationships, experience has shown that there is room to maneuver. The interrelationships are mediated by government policies and by such social institutions as family, community, and cultural traditions and practices. By adopting wise social and economic policies now, responsible governments can make the difference.

Population growth rates can be braked faster and fewer numbers added in developing countries than now projected by programs shown to have worked in reducing high fertility: basic health, family planning, and education services made accessible to all, coupled with emphasis on development strategies that expand employment opportunities as fast as possible and thus provide escapes from poverty. Similarly, proven management programs in both developing and developed countries can brake and reverse the depletion and degradation of natural resources.

In exploring these issues, this *Bulletin* begins with a look at the long history of concerns and debate about population growth and resources.

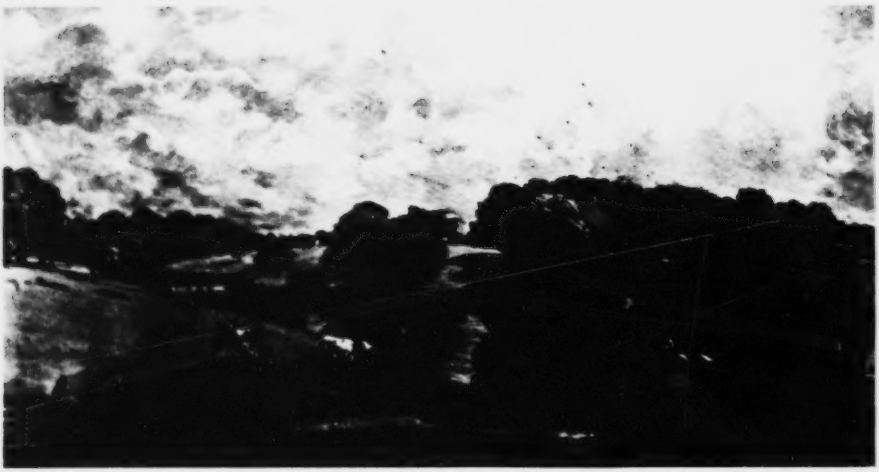
Intellectual Background

Concerns about population pressures on resources are more ancient than most people realize. Chinese writers at the time of Confucius inquired into the right balance of population and land to bring the greatest prosperity to the State. Plato estimated the ideal population of a Greek state, one that would be large enough for security and self-sufficiency but small enough to preserve civic cohesion, to be 5,040 landholding households.[1]

Classical and neoclassical economists

Over centuries of debate, prevailing opinion concerning population growth's effects has shifted back and forth with ideology and economic conditions. The classical economists—notably Adam Smith, Thomas Malthus, and David Ricardo—were reacting to the arguments of earlier Mercantilist writers of the 16th to 18th centuries. Mercantilists such as Jean Bodin, reflecting the rise of nation states and vigorous commercial expansion, believed, "One should never fear there being too many subjects or too many citizens, seeing that there is no wealth nor strength but in men."[2]

Malthus and other classical economists, writing at the start of the 19th century when accelerating population and industrial growth were raising demands for food faster than English agriculture could respond, saw real wages falling and food imports rising.[3] They emphasized the limits that scarce farmland imposed on agricultural expansion, arguing that applying ever more labor and other inputs to a fixed land base would inevitably encounter diminishing returns, reducing output per worker. The classical economists also stressed the tendency for population to rise with any widespread improvement in living standards, through lower mortality rates and



"Wivenhoe Park, Essex," by John Constable (1776-1837). Writing in England at the start of the 19th century, Thomas Malthus and other classical economists argued that a fixed land base imposed limits on meeting rising food demands generated by accelerating population and industrial growth.

earlier marriage. In their view, this tendency continually depressed real wages toward a subsistence level while rents to landowners grew.

This stress on the inherent limits to the availability of natural resources and consequent diminishing returns to other inputs and rising production costs is still the core of contemporary Malthusian perspectives. However, these concerns now encompass scarcities not only of agricultural land but also of exhaustible resources such as fossil fuels (oil, coal, natural gas) and limits on the capacity of global life-support systems to withstand human disruptions.

Most contemporary rebuttals of Malthusian viewpoints repeat objections that were first raised at least 150 years ago. The utopian Condorcet argued in 1795 that scientific advance would offset diminishing returns: "New instruments, machines, and looms can add to man's strength and improve at once the quality and accuracy of man's productions, and can diminish the time and labor that has to be expended on them . . . . A very small amount of ground will be able to produce a great quantity of supplies . . ., more goods will be obtained for a small outlay, the manufacture of articles will be achieved with less wastage of raw materials and will make better use of them."[4]

Marx argued that Malthus' argument was a rationale for class exploitation. As he saw it, the real cause of depressed wages was the increasing concentration of resources in the hands of capitalist proprietors. Nassau Senior asserted that improved living standards for the poor would not lead them blindly to expand their numbers but rather to restrict their fertility in order to preserve the gains they had realized.[5]

The views of 20th century neoclassical economists reflect the enormous 19th century expansion of land under cultivation beyond the borders of Europe, the diminished importance of agriculture in modern industrial economies, and a century of rapid technological progress and declining relative prices for resource-based commodities.

Neoclassical economic thought puts invested capital in place of natural resources at the center of attention. While still pessimistic about the consequences of rapid population growth, most neo-

classical economists saw as the danger of diminishing returns that the labor force would outgrow the stock of invested capital, so that workers would be employed, if at all, only at reduced real wage rates. However, since invested capital could be increased indefinitely through savings, output could always increase along with population, and—with the help of technological progress—outstrip it.

Neoclassical economic thought has discounted even natural resource constraints imposed by nonrenewable minerals. It emphasizes the adaptability of modern economies through market-induced substitution and innovation. If some resource costs rose, businessmen would reduce costs by substituting other materials and labor or capital. Consumers would also reduce purchases of commodities that use the resource intensively in favor of other kinds of goods. If the resource scarcity were local, rising prices would make imports from other regions more attractive and trade patterns would shift. Neoclassical economic models imply that if substitution possibilities remain sufficiently great, income per capita can be sustained with a rising population even if the resource is ultimately exhaustible.[6]

Technological change has understandably come to the forefront of modern economic thought. There is ample evidence that increasing resource scarcities, signaled by rising relative prices, induce innovators to develop and introduce new production processes. The original Industrial Revolution is often portrayed as a series of technical innovations induced by successive resource bottlenecks. For example, the depletion of English charcoal supplies hampered the ironmaking industries until Abraham Darby, who had used coke to smelt copper, developed a way to produce good quality iron in a coke oven. The resulting jump in demand for coal created another bottleneck: the need for power to run the pumps that kept coal mines dry. One English colliery in the early 18th century used 500 horses on the pumps. Newcomen's steam pump met the need, but led to a severe transport bottleneck as output expanded. This was resolved eventually by Stephenson's steam locomotive running on iron rails.[7]

Neoclassical economists also emphasize the ability of markets to adapt to resource scarcities over time. Anticipated future scarcities induce businessmen to hold supplies off the market in expectation of higher future prices, and to spend more to discover and develop new supplies. Even though those still unborn exert no market influence directly to preserve resources for their use, businessmen's anticipations of future demand represent them indirectly by bidding up the asset values of resource stocks.

These insights are valuable in explaining how market economies have dealt effectively with resource constraints. But most contemporary economists acknowledge that there are limits to their applicability. Prices can guide market adjustment processes only if resources can be bought and sold, which presupposes that they can be owned. Many important resources are not privately owned, usually because it is impossible to segregate one person's portion from another's and reserve it for exclusive use. Chief Seattle of the Dwamish and Squamish Indians of Puget Sound replied to U. S. President Franklin Pierce in 1855 when the government wanted to buy his tribe's land: "The idea is strange to us. If we do not own the freshness of the air and the sparkle of the waters, how can you buy them?" The air, the waters, the wealth of wild species, and still, in parts of the world, the grazing lands and forests belong to everyone.

Unless the community collectively exercises control over the use of such "common property" resources, through legal and regulatory restraints in modern states and through custom or the decisions of the leaders in traditional societies, scarcity feeds on itself. Users assume that if they take less of the depleted resource, others will just take more; if

they find ways to increase its availability, others will garner the fruits of their efforts. Or, if the resource is vast like the atmosphere, their small sacrifices to preserve it would have insignificant effects. Even if market processes could be relied on to deal effectively with privately owned resources, the importance of common property resources in our basic life-support systems gives grounds for concern about future scarcities in the face of increasing demands on them.

But market processes are also shortsighted about future private demands. A businessman who holds resources off the market for future sale ties up capital that could be profitably invested elsewhere, and expects an equivalent rate of return. Even if returns on alternative investment are no more than 7 percent per year, a businessman could only justify conserving a resource for 100 years if its value were expected to rise more than 800 times over that period.

Natural science views

Natural scientists see other limitations to neoclassical economic analysis of population and resources. Economic models are basically empirical approximations, and if extrapolated far beyond the range of known experience, they can be misleading—not least because they can conflict with the physical laws of nature. For example, typical "long-term" economic growth models imply that with the population growing at a constant rate, output will also settle down to an equilibrium rate of growth determined by the rates of technological advance and labor force increase.

This conflicts with scientists' knowledge of equilibrium in finite natural systems. If world population were to grow continuously at the 1987 rate of 1.67 percent per year, then the earth's land area, excluding Antarctica, would be packed solid with 427,383.8 billion people by the year 2667—85,477 times the 5 billion of 1987. Although Antarctica is chilly, in a pinch it could provide additional standing room—for seven more years. The year 2674—687 years into the future—may seem remote, but if we look back the same number of years into the past, we find Marco Polo returned to Venice from his journeys in China, the great cathedrals of Notre Dame and Chartres already dedicated, and the era of modern warfare opening in Europe with gunpowder introduced from the East.

Continuing exponential growth of output is, of course, equally impossible. Automobiles, increasing more rapidly than the human population, would exhaust all available space much sooner, starting from certain cities where they already have done so.

Scientists also see limits to substitution possibilities. To an extent, labor and capital inputs can substitute for materials in the manufacturing process, but no amount of additional kneading and baking will produce a loaf of bread from an ever-decreasing amount of wheat. More fundamentally, energy is essential to all life-sustaining processes, and all such processes dissipate useful energy. Substituting for the decreased richness or accessibility of mineral ores generally requires more energy per unit of output. Substituting for the decreased availability of agricultural land by raising yields per hectare generally requires more energy per unit of output, in the form of labor, chemical, and machinery inputs. While energy can be used more efficiently in these processes and also in the conversion of energy sources to useful forms, nothing could be substituted for increasingly scarce energy if low-cost, concentrated sources were depleted.

Biologists sometimes apply the concept of carrying capacity to questions of human population pressure. In population biology, carrying capacity is the maximum population of a species that its habitat can sustain. In density-dependent species, like fruit flies in a bottle, it is the limit to which the population will grow. Efforts have been made to estimate the size of human populations relative to land's carrying capacity. At the global level, estimates range from a maximum

carrying capacity of 7.5 billion to over 40 billion people.[8]

A recent large-scale study by the Food and Agriculture Organization (FAO) estimated potential agricultural production in 117 developing countries on the basis of climate, soil and land-use maps, and three alternative levels of technology.[9] The results were compared with the food requirements of projected populations in 1975 and 2000. In all these countries together, potential agricultural output was estimated to be four times the population in 2000 at an intermediate level of technology (the use of basic fertilizers and chemicals, some improved seed varieties, and simple conservation methods). However, the study estimated that 36 countries, mostly in Africa, Asia, and Central America, would be "critical" in the sense that their populations in 2000, totaling 480 million people, would exceed potential food production with intermediate technology.

Such an application of the carrying capacity concept is misleading. Many "critical" countries that lack agricultural resources, such as Kuwait and Korea, can readily trade for food with nonagricultural exports. By adopting smaller geographical units and ignoring trading opportunities, the number of "critical" regions can be made to increase markedly.

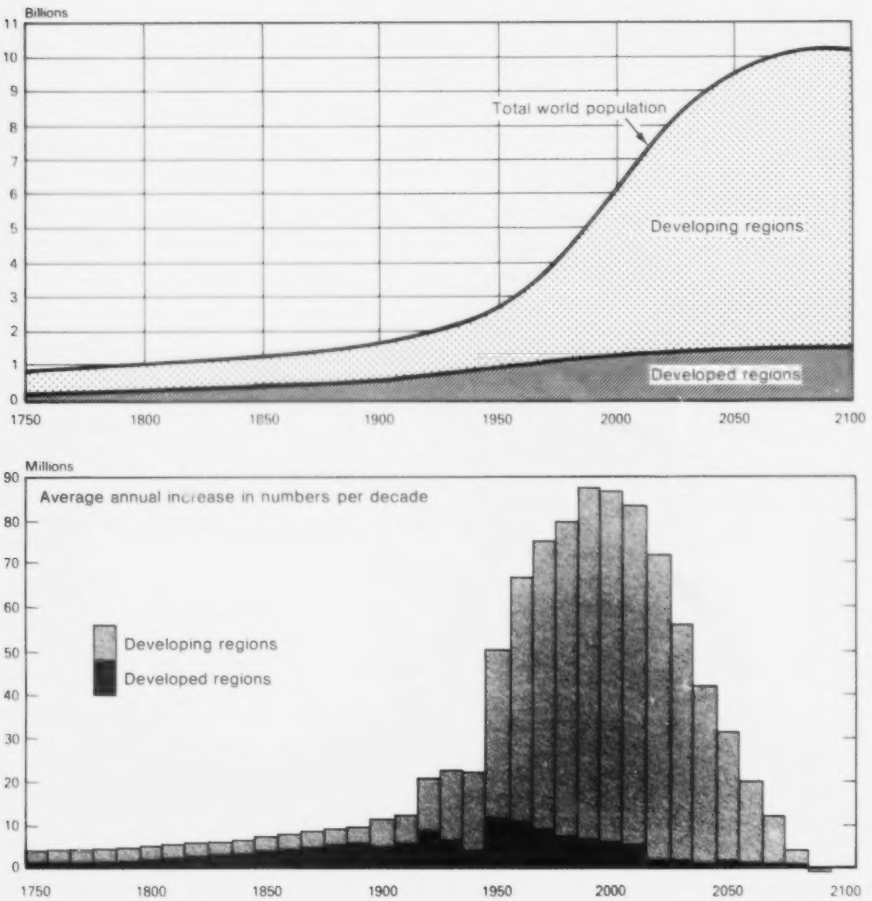
Furthermore, the implicit analogy to nonhuman species, which don't approach man's capacity for modifying both his environment and his way of using it, is faulty. From the beginning, humans have adapted to population pressures. Hunting societies used fire to drive game and reduce cover, altering the landscape in the process. When prized large mammals became scarcer, these people broadened their diet to include more plentiful food sources.[10] Technological and cultural responses to population growth have been accelerating ever since. Agriculture developed, largely in response to population density, from shifting cultivation with long fallow periods, to short fallow and cropping rotations dependent on organic manuring, to intensive monocultures using high-yielding seed varieties, irrigation, chemicals, and energy inputs.[11]

Moreover, social mechanisms that regulate population growth are found in both traditional and modern societies. Outmigration has always been a response to population pressure. Prolonged breastfeeding and sexual taboos restricted births in hunting societies to well under half the biological potential. Fertility in preindustrial Western Europe was restrained by inheritance laws that delayed marriage. Contemporary societies also resort to contraception and abortion. In societies subject to high mortality rates, mechanisms have evolved to keep fertility high, such as early and universal marriage. Unlike other species, humanity controls to a high degree its own demography and its resource base.

Such adaptations by no means ensure against stress, including environmental damage and poverty. Natural scientists also point out broader stresses against natural resource limits. Human expansion impinges on ecosystems functioning on both local and global scales. A large and increasing share of the biosphere's net primary production has been appropriated for human use.[12] Net primary production is the increment in biomass created by fixing solar energy through photosynthetic conversion of carbon dioxide into usable carbon compounds. Diverting more for human use leaves less for maintenance of the rest of the biosphere. Among the consequences of this increasing appropriation are destruction of habitat for other species, leading to simplified and impoverished ecosystems and accelerated rates of extinction.[13]

Examples of disturbed natural systems are widespread. Worldwide, the burning of fossil fuels for energy and other processes leading to large emissions of "greenhouse gases" have disrupted the carbon cycle and global heat balance, setting off a process of substantial climate modification and warming. Scientists emphasize that they cannot predict with any certainty what will happen as such critical natural systems are dis-

Figure 1. World, Developing and Developed Regions, Population Growth: 1750-2100



Source: Thomas W. Merrick, with PRB staff, "World Population in Transition," *Population Bulletin*, Vol. 41, No. 2 (April 1986) Figure 1, p. 4.

turbed and that by the time the consequences are evident, the changes may be irreversible. The ecological limits being tested are not protected by rising prices, since the threatened resources—biological diversity, climate, and communal woodlands—are mainly in the public domain.

The Population Prospect

Although the debate about population growth and resources is long-standing, recent demographic developments are

unprecedented. When Malthus wrote at the start of the 19th century, world population was growing slowly in absolute and relative terms. World population was about 1 billion, and it took 130 years to add another billion. The third billion was added in 30 years, by 1960, the fourth billion was reached by 1974, 14 years later, and the fifth in 1987, 13 years later. As Figure 1 (page 9) illustrates, the scale of current population growth is unlike anything seen before. More than 85 million people, the equivalent of a new Mexico, are added to the world's population each year.

Also unique is the shift in population growth to the less developed countries. Until the 1930s, population grew more rapidly in the richer countries. High mortality checked growth in poorer countries, but since World War II, antibiotics, vaccines, insecticides, and improved sanitation and nutrition have markedly reduced their death rates. Birth rates have fallen much more slowly, as marriage ages have gradually risen and contraceptive use has spread. Since 1950, 85 percent of the total population increase has been in the Third World.

Dramatic as these changes are, they are overshadowed by the downturn in the world population growth rate in the early 1970s. Annual growth touched 2 percent in the late 1960s, implying that population would double in less than 35 years, but the rate then fell back. Thus, a progression of ever-shortening doubling times that began in prehistoric times has finally been reversed. This change does not relieve the pressures of rapid growth: *absolute* annual increments are projected to rise to a peak of about 90 million in the late 1990s. But we now see the passing flood crest of population growth.

As of 1987, the world's demographic future holds another doubling of population and increasing divergence between developing countries other than China and the industrialized world. Current United Nations medium projections assuming fairly rapid declines in birth and death rates in developing countries foresee population ultimately stabilizing toward the end of the next century at about 10.2 billion. They project that only 256 million more people will be added in the developed countries between 1985 and 2000, while over 5 billion additional people will inhabit the rest of the world by the end of the 21st century (see Table 1).

Fertility in the developed world has already fallen below the replacement level of 2.1 births per woman and only the momentum of an unbalanced age distribution and immigration keep population growing. China, home to over a fifth of the world's people, has nearly reached a similar position after a precipitous decline in fertility (and also in mortality).

Other developing countries show much greater differences. Africa, the Moslem Middle East, and Western Asia still have birth rates higher than recorded anywhere else in the world *before* the onset of demographic transition (except in the United States) and population growth rates have been rising as mortality declines. Latin America and the rest of Asia are in demographic transition from high to low birth and death rates, but at speeds that vary considerably from country to country. In many of the countries that have only recently entered the demographic transition, such as Mexico, Thailand, and Indonesia, birth rates have dropped by more than one point per 1,000 population per year during some five-year periods since the 1960s, which is two to four times faster than earlier declines in Europe and the United States. In other developing countries, such as Bolivia, Guatemala, and Bangladesh, birth rates have declined little.

Long-run projections for the developing countries are uncertain. Overall birth rates are still high and the gap between birth and death rates is generally still large. Many trajectories of decline in population growth are plausible. Nearly 40 percent of developing country people are less than 15 years old and their fertility as adults will make an enormous difference. The medium UN projection cited above assumes that world fertility will be

Table 1. World, Developing and Developed Regions, Projected Population Growth: 1985-2100

(Numbers in millions)

Region	1985	2000	2025	2100
World total	4,837	6,122	8,206	10,185
Developing regions	3,657	4,837	6,779	8,748
Africa	555	872	1,617	2,591
Asia (minus Japan)	2,697	3,419	4,403	4,919
Latin America	405	546	779	1,238
Developed regions	1,181	1,284	1,407	1,437
Europe, USSR, Japan, Oceania[a]	917	987	1,062	1,055
North America[b]	264	297	345	382

Source: Merrick, "World Population in Transition," Table 1, p. 12.

[a]Oceania includes Australia and New Zealand.

[b]North America = Canada and the United States.

at replacement level by 2035; just a 30-year delay would mean an ultimate population size 4 billion larger.[14]

According to projections to 2025, 85 percent of the population increase in the Third World will be in urban areas: the urban population will grow by more than 3 percent per year. Large cities will grow even faster. In 1985 there were 28 Third World cities with more than 4 million inhabitants, home to 222 million people. By 2000 there will be 50 such agglomerations, with a total population of 455 million.[15] This expansion will put enormous pressure on urban environments. Yet, rural populations will also expand until well into the next century, in total by at least a half billion people.

Consequences of Population Expansion

Living standards

The demographic flood now cresting has not been contained by the "positive checks" that Malthus feared: famine, war, and pestilence. Rather, it has been the "preventive checks" of later marriage and falling fertility within marriage that have reduced growth rates, even as mortality has continued to decline. Modernization and rising living standards have checked population growth, not poverty and resource limits.

Although rapid population growth has strained the capacities of developing economies to provide employment, to raise agricultural output, and to make the investments necessary for expanding cities to function, living standards have risen in almost all countries. As Table 2 shows (page 12), over the period of maximum growth rates (1960-1984), per capita income and agricultural production, school enrollment and literacy, life expectancy and other measures of welfare, all improved. Population increase may have enormously complicated the task of development, but clearly has not precluded some degree of success.

Such improvements are cited as evidence that population growth does not impede economic progress, but the question remains whether progress would have been faster had population increase been slower. This question cannot be answered with certainty, but the balance of expert opinion says yes.[16] Output per person would probably have increased faster, because more capital per worker would have been accumulated and expenditures per person on

Table 2. Socioeconomic Indicators, Selected Countries: About 1960 and 1984

Country	Population (millions) mid-1984	Average annual growth of GNP per capita (percent) 1965-84	Average index of food production per capita (1965-67 = 100) 1982-84	Life expectancy at birth (years) 1960	1984
Low-income	2,389.5	2.8	111.4	36	60
China	1,029.2	4.5	138.2	51	69
India	749.2	1.6	117.7	42	56
Kenya	19.6	2.1	72.2	43	54
Middle-income	1,187.6	3.0	108.2	49	61
Brazil	132.6	4.6	131.1	56	64
Egypt	45.9	4.3	94.6	45	60
Indonesia	158.9	4.9	140.4	40	55
Mexico	76.8	2.9	101.9	56	66
Nigeria	96.5	2.8	85.4	34	50
Industrial market	733.4	2.4	117.9	70	76
Japan	120.0	4.7	97.4	67	77
United States	237.0	1.7	119.7	70	76
East European nonmarket	389.3	—	117.4	66	68
USSR	275.0	—	114.1	68	67

Sources: World Bank, *World Development Report 1978* and *World Development Report 1986* (New York: Oxford University Press, 1978, 1986); UNESCO, *1985 UNESCO Statistical Digest* (Paris: 1985).

education and health would have been greater. However, expert opinion today emphasizes that other factors, such as economic policies and political institutions, influence rates of economic progress at least as much as variations in population growth rates do.

Poverty and inequalities

Improved living conditions for the "average" person also divert attention from the growing numbers whose living standards are below stringent poverty levels. The World Bank has estimated that in 1978, 780 million people outside China and the centrally planned economies lived in absolute poverty, barely able to survive.[17] Despite reductions over time in the proportion of the world population suffering such deprivation, population growth has pushed the numbers upward. By 1987 the world total of such deprived people probably exceeds one billion. It is important to recognize that widespread chronic malnutrition and famines in the Third World are typically not due to global, regional, or even national food shortages, but rather to poor households' inability to purchase the food that is potentially available.

The difference between average living conditions and those of the poor is affected by rapid population increase, partly because, except for those in worst need, poor households tend to have more children to support than those who are well off. Also, by depressing wages relative to rents and returns to capital, rapid population growth devalues what poor households have to sell—their labor. Property owners gain relative to wage earners when the labor force grows quickly. However, politics and economic policies influence the distribution of income within countries far more than population growth rates do.

Poverty adds considerably to resource pressures in the Third World. Poor households are often virtually forced to overuse natural resources for daily subsistence. Thus, landless farmers colonize tropical forests, or grow cassava

Infant mortality rate (under age one)		Number enrolled in school as percent of age group				Adult literacy rate (percent)	
		Primary		Secondary			
1960	1984	1960	1983	1960	1983	1960	1985
142	72	30	91	2	31	10	—
51	36	—	104	—	35	—	69.3
139	90	41	85	23	34	24	43.5
—	92	47	100	30	19	—	59.2
142	72	79	105	12	47	61	—
70	68	95	102	11	42	61	77.7
109	94	66	88	16	58	20	44.5
82	97	67	115	6	37	47	74.1
74	51	80	119	11	55	62	90.3
207	110	36	98	3	—	25	42.4
25	9	108	102	53	85	—	—
31	6	103	100	74	94	98	99.9
26	11	118	100	64	—	98	99.5
—	19	—	104	—	91	—	—
—	—	100	106	73	99	98	99.8

and maize on highly erodible hillsides. Rural households in fuelwood-deficit countries strip foliage and burn crop and animal residues for fuel rather than using them for fertilizer and this contributes to desertification. Underemployed men in coastal villages overexploit already depleted inshore fisheries. A cycle of poverty and natural resource degradation is established.

Table 3 (page 14) presents 1980 data on the concentration of landholdings in developing countries, one important indicator of poverty and inequality. In Brazil, for example, a small fraction of landholders (16 percent) commands a large share of agricultural land (87 percent), and this pattern is typical. Actual inequality is substantially greater than such data indicate, because many smallholders only sharecrop or lease their holdings and a substantial percentage of rural households have no land at all. Much of the expansion of agricultural area in recent decades has not been added to small subsistence holdings but rather to large estates.[18] In countries such as Brazil and Guatamala, unequal distribution rather than overall land shortage creates the most severe pressures on marginal areas.

Population growth has also helped to widen disparities in income among nations. In the past 20 years, low-income countries as a group have actually raised total output, measured by gross national product (GNP), more rapidly than rich countries, but most of these gains have been offset by higher population growth rates. In per capita terms, the relative gap has narrowed negligibly while the absolute gap has widened substantially. Compare India and the United States over the period 1965 to 1984. Total GNP grew faster in India, but because population also grew twice as fast, India's average annual per capita income growth, 1.6 percent, was virtually the same as that of the U. S., 1.7 percent (see Table 2). In constant prices, per capita incomes were $190 and $10,985 in the two countries in 1965. By 1984, per

Table 3. Distribution of Agricultural Holdings and Area, by Size of Holdings, Selected Countries: 1980

Country	Size of holdings					
	Under 5 hectares		5-50 hectares		Over 50 hectares	
	Percent of holdings	Percent of area	Percent of holdings	Percent of area	Percent of holdings	Percent of area
Brazil	37	1	45	12	16	87
Guatemala	78	11	19	25	3	64
India	91	51	9	46	0	3
Nepal	97	71	3	29	0	0
Niger	58	33	42	67	0	0
Pakistan	73	34	26	57	0	9
Panama	66	4	27	30	7	66
Philippines	86	51	14	37	0	12
Thailand	72	39	28	61	0	0
Turkey	62	20	37	68	1	11
Uruguay	12	0	46	4	42	96

Source: International Institute for Environment and Development (IIED) and World Resources Institute (WRI), *World Resources 1987* (New York: Basic Books, 1987) Table 19.2, p. 278.

capita income had grown by only $70 in India, in contrast to a $4,400 increase in the U. S.

These disparities have fundamental implications for resource use. In the United States and other rich countries, because the average diet contains so much meat, each person consumes (directly and indirectly) enough grain to feed four Indians, and aggregate cereal consumption is a large fraction of the world total. The same holds true for commercial fuels, metals, wood, and paper and other resource-based commodities. As Table 4 demonstrates, the developed countries use most of the world's resources, despite their much smaller share of total population (17 percent in 1984) and lower population growth rates.

Many of the demands on natural resources in the developing countries thus emanate from the developed world. The developing countries are substantial net exporters of agricultural commodities, although they have become net importers of foodgrains. Similarly, huge volumes of tropical hardwoods and other forest products, beef cattle, minerals, and petroleum products flow to meet the demands of industrial countries, in exchange for processed manufactures. Much of the capital and technology for the exploitation of developing countries' natural resources also emanates from the industrial world. Resource pressures in the developing countries should by no means be attributed solely to high rates of population growth.

Effects on renewable resources

Economic and demographic expansion has transformed the resource base. This base consists of both "nonrenewable" or seemingly exhaustible resources like fossil fuels, metals, and nonmetallic minerals (dealt with in the next section) and renewable resources: land, water, and the nonhuman species like trees, plants, animals, fish, birds, and insects who share these ecosystems with humans and on whom humans in turn depend. Perhaps most transformed of renewable resources has been the land.

Effects of increasing cropland. Up until World War II, increasing agricultural demands fueled by population and economic growth were met mainly by expanding the area under cultivation. Table 5 (page 16) shows that 963 million hectares, or almost two-thirds of the 1.5 billion hectares farmed as cropland by 1980, was brought into production after

Table 4. Consumption of Major Resource Commodities, by Region: 1984

Population and resource	Developing countries	Developed countries	USSR and Eastern Europe
Population (millions)	3,592	792	388
Percent of total	75.3	16.6	8.1
Commercial fuels (metric tons of coal equivalent, thousands)	1,953,187	4,603,777	2,241,617
Percent of total	22.2	52.3	25.5
Per capita (kilograms)	543.8	5,816.0	5,777.4
Steel (metric tons, thousands)	200,656	313,799	193,87
Percent of total	28.6	44.3	27.4
Per capita (kilograms)	55.9	396.2	499.7
Cereals (Production) (metric tons, thousands)	929,000	595,704	276,980
Percent of total	51.6	33.1	15.4
Per capita (kilograms)	250.3	752.2	713.9
Wood (cubic meters, thousands)	91,400	363,000	178,600
Percent of total	14.4	57.3	28.2
Per capita (kilograms)	24.6	458.3	460.3

Source: United Nations. 1983 84 *Statistical Yearbook* (New York: 1986).

1850, and most of it—1.2 billion hectares—by 1950. The table also shows that this expansion, especially from 1850 to 1950, was by no means limited to the "New World." Vast areas were cleared and put to the plow in the USSR, in South Asia, and in Africa, as well as in the New World of North and Latin America. Pioneers were at work clearing forests in southern Burma, battling malaria in the shadow of the Himalayas, and pushing cultivation northward into Sahelian pastoral ranges in Africa. Were comparable data available for the century before 1850, they would show an equally dramatic increase in the area under cultivation. By 1980 global cropland had increased 179 percent over the figure for 1850.

The counterpart has been a substantial reduction in the extent of other ecosystems—temperate and tropical forests, grasslands, and wetlands (see box on India, page 18). Almost a billion hectares of forests and woodlands have been cleared since 1850, about half the total reduction in forest area since prehistoric times. Cumulatively, a greater percentage of the original temperate forests have been removed than those covering the tropics, but since World War II—the period of massive population increase in the developing countries—the locus of deforestation has shifted. Temperate forest area is stable, but deforestation in the tropics has accelerated. In the 1980s, according to FAO estimates, more than 11 million hectares—the area of Pennsylvania—have been deforested each year in the tropics.[19] This represents an annual rate of only 0.6 percent of the total tropical forest area, because in large countries such as Brazil, Indonesia, and Zaire, enormous forests remain, even though deforestation in those three countries alone totals over 2 million hectares each year. In other countries, the conversion rate is much higher. Cote d'Ivoire, which at 3.0 percent in 1987 has one of the world's highest rates of natural increase (birth minus death rates), is losing forests at the rate of 5.9 percent annually. Deforestation is also rapid in Costa Rica (3.9 percent a year), Haiti (3.1 percent), El Salvador (2.9 percent), and Nicaragua (2.7 percent), where natural increase rates range upward from 2.3 percent a year.

Table 5. World Land Use, by Region: 1850-1980

Region and land type	Area (million hectares)				Percent change 1850-1980
	1850	1900	1950	1980	
Ten regions, total					
Forests and woodlands	5,919	5,749	5,345	5,007	−15
Grassland and pasture	6,350	6,284	6,293	6,299	−1
Cropland	538	773	1,169	1,501	179
Tropical Africa					
Forests and woodlands	1,336	1,306	1,188	1,074	−20
Grassland and pasture	1,061	1,075	1,130	1,158	9
Cropland	57	73	136	222	288
North Africa and Middle East					
Forests and woodlands	34	30	18	14	−60
Grassland and pasture	1,119	1,115	1,097	1,060	−5
Cropland	27	37	66	107	294
North America					
Forests and woodlands	971	954	939	942	−3
Grassland and pasture	571	504	446	447	−22
Cropland	50	133	206	203	309
Latin America					
Forests and woodlands	1,420	1,394	1,273	1,151	−19
Grassland and pasture	621	634	700	767	23
Cropland	18	33	87	142	677
China					
Forests and woodlands	96	84	69	58	−39
Grassland and pasture	799	797	793	778	−3
Cropland	75	89	108	134	79
South Asia					
Forests and woodlands	317	299	251	180	−43
Grassland and pasture	189	189	190	187	−1
Cropland	71	89	136	210	196
Southeast Asia					
Forests and woodlands	252	249	242	235	−7
Grassland and pasture	123	118	105	92	−25
Cropland	7	15	35	55	670
Europe					
Forests and woodlands	160	156	154	167	4
Grassland and pasture	150	142	136	138	8
Cropland	132	145	152	137	−4
USSR					
Forests and woodlands	1,067	1,014	952	941	−12
Grassland and pasture	1,078	1,078	1,070	1,065	−1
Cropland	94	147	216	233	147
Pacific developed countries					
Forests and woodlands	267	263	258	246	−8
Grassland and pasture	638	634	625	608	−5
Cropland	6	14	28	58	841

Source: IIED and WRI, *World Resources 1987*, Table 18.3, p. 272

Such estimated changes in forest area can be misleading, because they conceal changes in the density of tree cover and the species composition. In general, as long as trees cover 10 to 20 percent, an area is considered forested, even though the density may have been reduced from several hundred to fewer than 50 trees per hectare and the mix of species altered significantly. In logged-over tropical moist forests, removing high-grade species has devalued remaining stands.

In semi-arid areas, tree density has fallen as the result of foraging and fuelwood collection.

The open savannahs of the Sahel are rapidly being stripped of their remaining trees; annual fuelwood consumption alone exceeds annual tree growth by an estimated 30 percent. In Niger, this figure is 200 percent; in northern Nigeria, 75 percent; in Ethiopia, 150 percent; and in the Sudan, 70 percent.[20] Worldwide, the FAO estimates that 1.5 billion of the 2 billion people who rely mostly on fuelwood are cutting wood faster than it is growing back, and 125 million in 23 countries even then cannot find enough wood to meet their needs.[21]

In the humid tropics, forest conversion has imperiled the principal source of the world's biological diversity: millions of plant, animal, and insect species whose potential value to agriculture, medicine, and science has yet to be explored. The total extinction rate cannot be reliably estimated, because scientists, who so far have classified 1.5 million species, do not even know whether another 1.5, 15, or 30 million species remain to be classified. Yet, the situation in critical ecosystems illustrates the larger problem.

In Madagascar, there were until recently 9,500 documented plant species and an estimated 190,000 animal species, 60 percent of them found only in or "endemic" to the island's eastern forest strip. Ninety-three percent of that forest has already disappeared, dooming at least 60,000 species.

In just 10,000 square kilometers of South Africa's Cape Floristic Kingdom, there are 6,000 known plant species, 70 percent of them endemic to that area. Encroaching farms, frequent fires, and invasions by exotic plants threaten at least 2,000 plant species (almost as many as exist in the entire United States).

The forests of western Ecuador are reputed to have once contained somewhere between 8,000 and 10,000 plant species, with 40 to 60 percent endemic. Estimates based on detailed inventories from sample plots suggest that there are 10 to 30 animal species for each plant species, implying a total species resource of about 200,000. Since 1960 virtually the entire forest cover of western Ecuador has been eliminated to make way for banana plantations and other land uses. Tens of thousands of species must have been eliminated.

Not all of the many exceptionally rich and endangered ecosystems are in the tropical forests. In Central Africa, for example, the 29,000-kilometer-square Lake Malawi contains more than 500 cichlid fish species (which include the tilapia species valuable for aquaculture), 99 percent of them endemic. This lake is one-tenth the size of the Great Lakes of North America, which contain only 173 species, only 10 percent of them endemic. Lake Malawi's fish are threatened by industrial pollution and the introduction of alien predator species.

Vast areas of wetlands have been drained in the last 150 years for farming, an estimated 50 million hectares in the United States alone, 20 million hectares in Europe and European Russia, plus tens of millions of acres in Asia.[22] In total, between 25 to 50 percent of the world's wetlands have been lost to date.[23] Wetlands are among the world's most productive ecosystems, along with tropical rain forests and coral reefs. Because their net primary productivity is so high, they provide habitat and breeding grounds for a disproportionate share of fish, crustaceans, amphibians, birds, and small mammals.

While the area under grasslands and pasturage seems more stable (see Table 5), the figures mask far-reaching changes. Millions of hectares of herders' best pasturage have been plowed up for cropland. At the same time, controlled grazing of domestic livestock has displaced herds of wild herbivores. Just as the bison, elk, and antelope have disappeared from the American plains, the enormous indigenous herds of browsing animals that amazed 19th century European explorers of Africa have dwindled to

Box 1. Long-Term Agricultural and Land-Use Trends in India

India, where there are data going back nearly a century, illustrates the interplay between population growth, agricultural production, and land use. In this century, the Indian population has more than tripled, from 240 million in 1900 to 800 million in 1987, an average growth rate of 1.38 percent per year. The agricultural response has been equally dramatic.

In the first half of the century, there was a massive expansion of cropland. Data for 183 districts in the northern Indian subcontinent, including parts of present-day Bangladesh and Pakistan, show that the arable area expanded by more than 25 million hectares or 45 percent between 1890 and 1970.[1] Other terrestial ecosystems—forests, woods, grassland, and scrub—were reduced by 30 to 40 percent (see table).

At the same time because of population growth, however, the land resource base diminished sharply in per capita terms. The availability of arable land declined from 0.39 to 0.23 hectares per capita and that of forests, woods, grasslands, and scrub shrank even more—from 0.49 to 0.13 hectares per capita.

Offsetting the growing scarcity of arable land was a substantial intensification of land use. Irrigated acreage expanded almost ninefold, from 2.6 million hectares in 1890 (4.4 percent of the arable area) to 22.3 million hectares in 1970 (26 percent of the arable area). The colonial government invested significantly in irrigation before independence in 1947, but the irrigated area doubled after 1950, in large part from private investments in tubewells.

Cropping intensity rose sharply on this irrigated acreage. The area left fallow fell from 17 to 10 percent between 1930 and 1970. The use of chemical fertilizers, largely in conjunction with high-yielding seed varieties, grew from a negligible amount to 8.6 million tons of nutrient used overall in India in 1985—160 kilograms per hectare of irrigated area.[2] After 1950 there was no further expansion of gross cropped area, but production rose due to significant improvements in crop yields.

The figure illustrates one result of this process. Independent India has succeeded in raising foodgrain production per capita by a modest amount since 1951. Its agricultural growth rate, while not exemplary, has equaled that of developing countries as a whole. Yet current per capita output remains well below the averages that prevailed in India in the early decades of this century.

Another result is increased pressure on the remaining nonarable land. Livestock, fed overwhelmingly on crop residues and natural forage rather than on fodder crops, increased in numbers proportionately with the expansion of cropped area. However, the

Land Use in 183 Districts of Northern India: 1890-1970

(Numbers in millions of hectares)

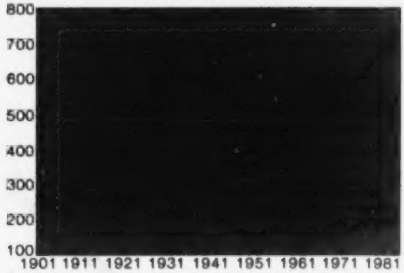
Land type	1890	1950	1970
Total area	155.6	155.6	155.6
Percent of total	100.0	100.0	100.0
Arable	59.1	73.1	86.1
Percent of total	38.0	47.0	55.3
Settled	2.8	4.2	6.6
Percent of total	1.8	2.7	4.2
Forest and woods	13.6	10.2	9.2
Percent of total	8.7	6.5	5.9
Interrupted woods	19.8	15.6	12.2
Percent of total	12.7	10.1	7.8
Grassland	22.3	18.5	14.2
Percent of total	14.3	11.9	9.1
Wetlands	4.9	3.6	3.2
Percent of total	3.1	2.3	2.1
Scrub and wasteland	28.7	25.8	19.6
Percent of total	18.5	16.6	12.6
Surface water	4.5	4.5	4.5
Percent of total	2.9	2.9	2.9

Source: See reference 1.

remnants mostly confined to parks and preserves.

Even with "controlled" grazing, the world's grasslands have markedly deteriorated under growing grazing pressures. Most rangelands are relatively susceptible to degradation, especially those in dry climates where plant growth is slow. Impoverishment and depletion of vegetative cover as the result of over-

Population and Per Capita Foodgrain Production in India: 1901-1985.



Source: See reference 2

ratio of livestock to people fell from 98:100 to 59:100 between 1900 and 1972 as pasturage provided by woods, grassland, and wastelands disappeared.

The transformation of these resources to cropland has affected the rural poor disproportionately, because for the most part it was a transformation from common property on which poor households depended to private property from which they were largely excluded. A study in seven Indian states, reported in 1986, found that poor households graze their animals on the commons from 70 to 90 percent of the time, compared to 20 to 40 percent for better-off rural households. Poor households obtain 60 to 90 percent of their fuel from the common lands, compared to 10 to 20 percent for other households. The rural poor also rely much more heavily on common land for gathering food, raw materials for handcrafts, and other subsistence.[3] The loss of natural ecosystems decreased living standards most for poor households with least control over the expanding cultivated area.

In the study areas of the seven states, 26 to 63 percent of common woods, grassland, wetlands, and wasteland had disappeared in the previous three decades, mostly through conversion to private cropland. Although some conversion programs were designed to alleviate rural poverty, most of the converted land ended up in the hands of better-off households. For India's rural poor a valuable and accessible resource disappeared, and thus the transformation has had less favorable long-term implications than suggested by trends in per capita foodgrain production.

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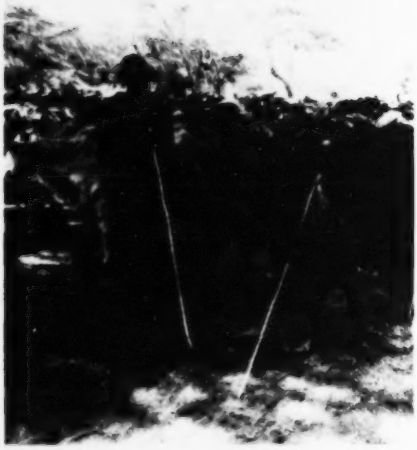
Farming in Rajasthan, India. Cropland expansion has sharply reduced woods, grassland, and other common land on which India's poor rural households depend.

stocking expose the soil surface to wind and water erosion, deplete the soil's organic content and nutrients, and impair its ability to hold water, a process known as desertification. As used in recent assessments, "moderate" and "severe" desertification generally involve productivity losses of up to 25 and 50 percent, respectively. More than 60 percent of the world's rangelands and at least 80 per-



Kenyan herders and their cattle. With growing grazing pressures, more than 60 percent of the world's rangelands are now moderately to severely desertified.

cent of African, Asian, and Middle Eastern rangelands are now assessed as moderately to severely desertified. About 65 million hectares of once productive land in Africa have become desert during the past 50 years.

As cultivation has extended from the plains and valleys into the once forested hills, an estimated 160 million hectares of upland watersheds in the tropical developing countries have been seriously degraded. Watersheds are seriously deteriorating in the foothills of the Andes and the Himalayas, in the Central American highlands, in the Central Highlands of Ethiopia, on densely populated Java, and elsewhere. Estimated rates of erosion for entire upland regions typically range from 30 to 60 tons per hectare per year. A recent World Bank study chose an average figure around 50.[24] In smaller, severely eroding watersheds, measured rates exceed 100 tons per hectare per year.

The effects are serious. Numerous studies show that yields decline at an increasing rate as fertile topsoil is lost. Eroded sediments are typically at least twice as rich in nutrients and organic matter as the soils left behind. Thin, nutrient-poor soils widely distributed in tropical and semi-arid areas are much more susceptible to productivity loss through erosion than temperate soils. In Indonesia, at least a million hectares have been rendered unproductive through erosion and 200,000 more hectares are being lost each year.[25] In Guatemala, 40 percent of the productive capacity of the land has been lost through erosion. In Turkey, 54 percent of the arable area is severely or very severely affected. In Mexico, roughly two-thirds of the land is moderately, severely, or totally eroded.[26] The FAO has estimated for all developing countries that, unless effectively checked, erosion will cost 20 percent of potential agricultural production by the end of this century.[27]

Off-site economic costs are also large. Reservoirs in the developing world are filling up with silt much faster than anticipated when the investments were made—typically, two or three times faster in South Asia—cutting short their usefulness for power generation and irrigation water storage when replacement costs are rising rapidly. Pakistan's Mangla Reservoir is an example. Built during the 1960s with a 100-year life expectancy, it may fill up with silt as much as 50 years ahead of its time. The giant Tarbela Dam, built during the late 1960s and early 1970s, will be useless within just 40 years at current rates of siltation. In India, the expected lifespan of the Tehri Dam, the world's sixth largest when finished, has already been reduced from 100 to 40 years due to deforestation of the watershed. These are merely indicative of downstream costs. Abraded turbines, increased water treatment costs, reduced fish populations, and changed river flows add to the damages of heavy sediment loads. Upstream devegetation also increases flooding after the rainy season and reduces dry season flows.

Effects of efforts to increase yields. Until 30 years ago, bringing new lands under cultivation was the principal means

Table 6. World Increases in Crop Area and Yields, by Region: 1964-1985

Region	Percent change in cropland 1964-66 to 1982-84	Percent change in yields 1964-66 to 1983-85	
		Cereals	Roots and tubers
World	8.9	58	21
Africa	13.5	13	22
Asia	4.1	77	58
North and Central America	7.8	44	23
South America	34.6	42	−1
Europe	10.5	76	19
USSR	1.3	35	13
Oceania	23.5	25	13

Source: IIED and WRI, *World Resources 1987*, Table 18.1 and 19.1, pp. 268 and 276.

of raising agricultural production. In most countries, yields increased gradually, if at all. Just since the early 1960s, the situation has reversed; cropland area has grown slowly in most countries, and the additional output has come mostly from increasing yields. Table 6 illustrates this phenomenon for the principal regions of the world. The reversal stemmed partly from increasing constraints on the availability of additional cropland in densely populated areas, such as China and South Asia, where cropped area is less than one-fifth of a hectare per person. It also stemmed from new opportunities: development of improved, high-yielding seed varieties, falling real prices for chemical fertilizers, and the availability of new synthetic pesticides. When combined on areas with assured water supplies, mostly through irrigation, this new technological package generated the "Green Revolution." This was a remarkable and critical achievement that supplied needed food and agricultural products at stable and declining real prices during a period of rapid population and economic growth. However, it also created pressures on the resource base.

The new technology and rising food demands encouraged large irrigation investments. Between 1965 and 1980, the total world acreage under irrigation increased 2.2 percent per year, reaching 15 percent of all cropland. Because inputs and the new technology were concentrated on irrigated land, it contributed most of the increased production. The costs of irrigating additional acreage have risen, while yields on large tracts of already irrigated land are declining due to salinization and waterlogging.

High water tables markedly concentrate salts in the root zones. In many irrigated areas without adequate drainage, in India and Pakistan for example, water tables have risen to within a few meters of the surface. Providing needed drainage can add substantially to water resource project costs and has frequently been deferred or neglected.

Inefficient water use in large irrigation projects—due to poor operation and maintenance, as well as to the absence of incentives for water conservation—have also exacerbated serious waterlogging and salinization problems. Excessive water losses in conveyance systems and field application have increased salt loadings in soils, drainage water, and aquifers. Many aquifers underlying irrigated areas have become so brackish that their usefulness has been impaired or destroyed.

This is not a new issue; 6,000 years ago on the Tigris-Euphrates floodplain in Mesopotamia, Sumerian irrigation practices led to a salt buildup in water and soils that contributed to the Sumerian cultural decline. Today, half the world's irrigated land is so badly salinized that yields are affected, with some 1 to 1.5 million hectares—mostly of prime agricultural land—becoming salinized each year. In India, waterlogging has made about 10 million hectares uncultivable and salinization threatens another 25 million hectares. In Pakistan, more than half the Indus Basin canal command system, some 12 million hectares, is waterlogged and 40 percent is saline. Salinization is also a persistent problem in the plains of eastern China, in Central Asia and Asia

Crop yields boosted by irrigation, as here in Pakistan, are now declining in many irrigated areas as a result of salinization and waterlogging.

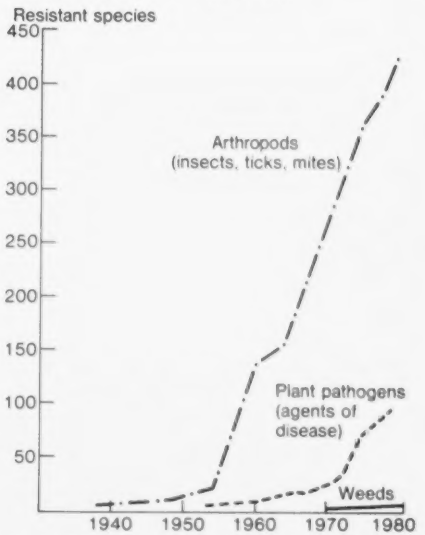
Minor, the Middle East and North Africa, and in North America. In the United States, including such highly productive areas as California's San Joaquin Valley, 20 to 25 percent of all irrigated land suffers decreased yields because of salinity.

Agricultural intensification has put other pressures on natural resources. Synthetic pesticides, use of which has risen sharply in the past 20 years, have had substantial ecological impacts. Previously unimportant insect species have emerged as major problems when their natural enemies have been reduced by pesticide applications. Many species have developed partial or complete resistance to a growing number of chemical pesticides. By 1980, 428 arthropods (insects, ticks, and mites) had developed resistance, along with more than 150 plant pathogens, 50 herbicide-resistant weeds, and 10 rodent and nematode (parasitic worm) species. Figure 2 shows how dramatically resistance has increased in recent years. Some crafty arthropods have been able to overcome the toxic effects of every pesticide to which they have been exposed, finally forcing farmers to abandon the crops on which they prey.[28]

Other environmental effects are also important. The World Health Organization estimates that hundreds of thousands of people die each year from acute pesticide poisoning. Through airborne drift, runoff into aquifers and drinking water supplies, residues on foodstuffs and other routes, chronic pesticide exposure is widespread and the risks uncertain. In the developed countries, most pesticides in use have not been thoroughly screened for health hazards, and developing countries still use those that have been banned elsewhere as excessively risky. Because malnutrition, infectious diseases, and other health problems are widely prevalent, developing country populations are particularly susceptible to pesticides' effects on the immune system.[29]

In sum, the fivefold increase in popu-

Figure 2. Species Resistant to Pesticides: 1940-1980



Source: G.P. Georghiou and R.B. Mellon, "Pesticide Resistance in Time and Space," in G.P. Georghiou and Tetsuo Saito (eds.), *Pest Resistance to Pesticides* (New York: Plenum Press, 1983) pp. 1-46.

lation since Malthus wrote has been accommodated with generally improving living conditions, although a billion people—the world's total population when he wrote—suffer severe deprivation and poverty, while another billion enjoy affluence he could not have imagined. A much larger share of the world's renewable resources—waters, soils, and living organisms—has been pressed into man's service. They have yielded up increasing production, but not without significant sacrifices of current and future productivity.

Effects on nonrenewable resources

Modern industry is based largely on minerals: fossil fuels, metals, and nonmetallic minerals. These are nonrenewable in the sense that supplies are extracted mostly from deposits formed by extremely slow geologic processes. However, metals can be recycled and hydrocarbons produced from plants if deposits become scarce enough. Nonrenewability is largely an economic concept.

Industrialization has enormously increased the production and use of many minerals. World steel output has risen 70 times over in this century. Aluminum output has risen more than 1,700 times. Production of some minor metals, such as molybdenum, has grown even more rapidly from small beginnings. Fossil fuel energy use also expanded rapidly. While coal production has increased only about seven times over this century, petroleum production has risen 125 times, an average annual growth rate exceeding 6 percent.[30]

This phenomenal growth is linked primarily to increasing per capita incomes and consumption standards in wealthy countries and only secondarily to population growth in the poorer countries, where food accounts for at least two-thirds of people's consumption budgets and agricultural production technologies are relatively labor-intensive.

Cumulative mineral production over these years has exceeded the known reserves at the beginning of the century by huge margins. Yet, far from running out, stocks of almost all minerals have increased. Table 7 demonstrates with selected minerals that even from 1950 to 1980, production virtually exhausted the initial reserves but reserves nonetheless were much higher at the end of the period. In other words, mineral reserves apparently increase in pace with the rate of extraction.

Table 7. World Reserves and Cumulative Production of Selected Minerals: 1950-1980

(Million metric tons of metal content)

Mineral	1950 reserves	Production 1950-80	1980 reserves
Aluminum	1,400	1,346	5,200
Copper	100	156	494
Iron	19,000	11,040	93,466
Lead	40	85	127

Source: William Vogeley, "Nonfuel Minerals and the World Economy," in Robert Repetto (ed.), *The Global Possible: Resources, Development, and The New Century* (New Haven, Conn.: Yale University Press, 1985).

This apparent paradox is easily dispelled by realizing that stated reserves are like a working inventory of materials known to be available and economically suitable for extraction. Unlike total mineral "resources," which refer to the amounts of materials physically present in the earth's crust, reserves are conventionally defined as the quantities known with reasonable certainty to be economically recoverable with available technology and at specified prices. The distinction is illustrated in Figure 3 (page 24), which depicts reserves as the subset of total resources with the most firmly established economic value.

Mineral reserves depend on prices, technology, and knowledge. As mineral prices rise or extraction costs fall, reserves usually increase because submarginal deposits become economical to recover and more exploration becomes worthwhile. There have been enormous improvements in the technologies used

Figure 3. Total Resource Base

Source: Donald A. Brobst, "Fundamental Concepts for the Analysis of Resource Availability," in V. Kerry Smith (ed.), *Scarcity and Growth Reconsidered* (Baltimore: Johns Hopkins Press for Resources for the Future, 1979) Figure 5.2.

to locate, extract, refine, and process mineral deposits that have made it feasible to exploit ores of much lower grade and to extract oil from the ocean depths and frozen north.

For this reason, although current production depends on such less accessible resources, minerals need not and have not become more scarce in an economic sense. Defining and measuring economic scarcity is not altogether straightforward. Increasing scarcity means that we must give up more of something else we value, but what? Our labor? Our capital? Our command over other commodities? Several measures of scarcity have been proposed and applied to mineral supplies. An influential 1963 study of long-run changes in resource scarcities by Harold Barnett and Chandler Morse relied mainly on trends in labor and capital costs in extractive industries.[31] An alternative measure is the relative prices of resource commodities, but again the question arises: "relative to what—the prices of nonextractive commodities or the price of all goods and services?" It could matter, because productivity has increased faster in industries producing commodities than in those providing services. Still other measures, such as the trend in rents paid to resource owners, can be defended on the Ricardian argument that the prices needed to justify exploitation of lower-grade deposits would provide increasing rents to owners of higher-grade reserves.

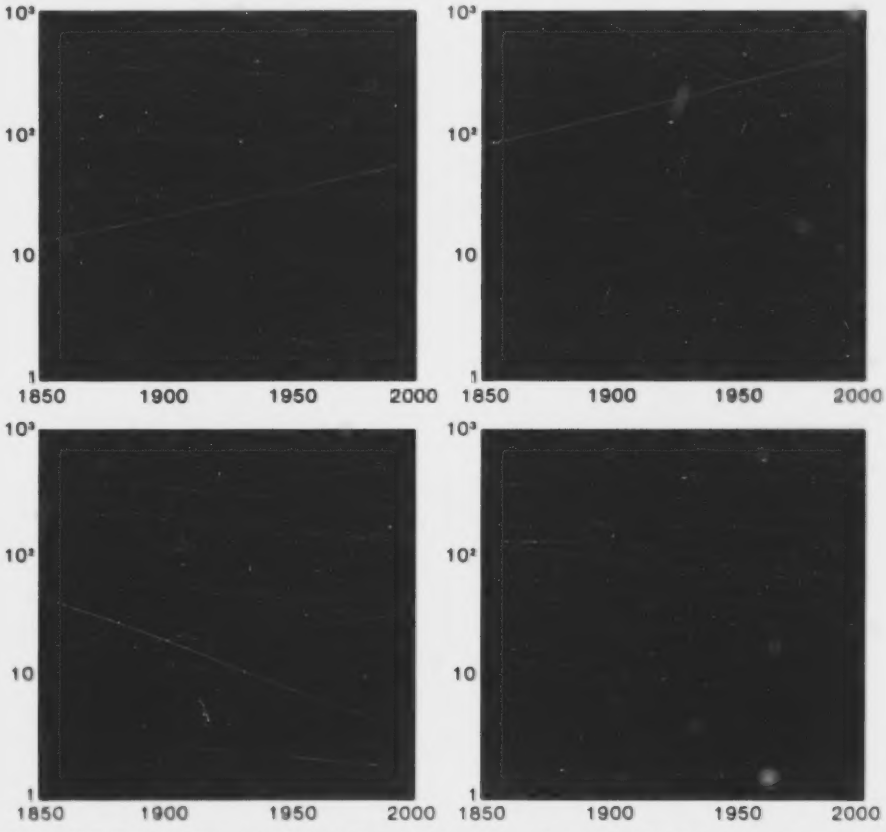
No single measure can give a completely reliable indication of trends in scarcity under all conditions. For example, improved technologies kept the costs of catching and killing whales from increasing even as whales approached extinction, suggesting a flaw in that measure. Commodity prices are influenced by changes in market structure, government policies, and prevailing expectations about the future that may have little to do with current scarcities. The steep rise in oil prices engineered by OPEC in 1973 reflected a change in market structure rather than a sudden large change in petroleum availability. Also, rents may actually decrease as an exhaustible resource becomes sufficiently scarce that substitutes become more economical.

Despite these potential ambiguities, the empirical record is relatively clear. In economic terms, exhaustible resources have not become significantly more scarce over the past century and, by some measures, most have become less scarce. This is illustrated in Figure 4, which shows U. S. prices in constant 1967 dollars from 1870 to 1985 for nine major metals, energy resources, and for sulfur and phosphate rock, major components of fertilizer. In constant dollars, these prices are generally no higher, and in many cases lower, than in the early decades of this century. Even the sharp rises in energy and other resource prices during the 1970s have been partially reversed so far in the 1980s.

Energy market changes during the past two decades illustrate the uncertainties surrounding resource scarcities. Their growing share of world production enabled OPEC producers to take control of petroleum supply from the international oil companies in the early 1970s, successfully raising prices from around $3 to about $13 per barrel. Although this reinforced world inflationary forces, real

Figure 4. U.S. Relative Price Trends for Major Resources: 1870-1985

(Prices in constant 1967 dollars)

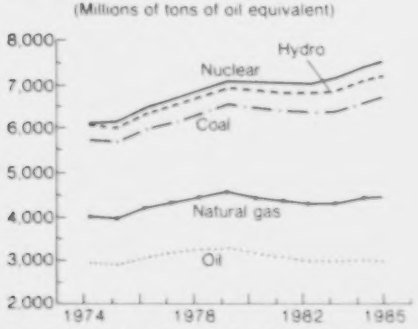


Sources: 1870-1976: Ulrich Petersen and R. Steven Maxwell, "Historical Mineral Production and Price Trends," *Mining Engineering*, Vol. 31, No. 1 (January 1979) pp. 30-31; 1977-1985: Commodity Research Bureau, *1985 CRB Commodity Year Book* (Jersey City, N.J.: 1985); and World Bank, *Commodity Trade and Price Trends* (Washington, D.C.: 1986).

petroleum prices stayed constant from 1975 until 1979, when the war between Iran and Iraq disrupted markets and allowed OPEC to raise prices to a peak of $34 per barrel in 1982, even though marginal production costs in the Middle East remained in the vicinity of $2 to $3 per barrel.

Market adjustments have been vigorous although sometimes painful. High oil prices stimulated exploration and production outside OPEC, in Mexico, the North Sea, and elsewhere. By 1985 OPEC's world market share had fallen to less than one-third (17 million barrels per day) from over half (31 million barrels per day) in 1973. Moreover, oil's overall share of commercial energy consumption fell sharply from 46 percent in 1974 to about 38 percent in 1985, as natural gas, coal, and hydroelectricity captured oil's industrial and utility mar-

Figure 5. World Commercial Energy Consumption: 1974-1985



Source: Christopher Flavin, Denis Hayes, and James Mackenzie, *The Oil Rollercoaster: A Call to Action* (Washington, D.C.: Fund for Renewable Energy and the Environment, 1987).

kets (see Figure 5). Finally, energy itself lost market share. In the United States, for example, total commercial energy use fell slightly between 1973 and 1986, despite a 34 percent increase in real GNP.

Severe recessions in 1975 and 1982 and relatively slow growth in the world economy during the past decade also cut energy demands. These forces combined to create increasing excess capacity among OPEC producers and excess supply on world oil markets in the 1980s. Members of the OPEC cartel were unable to agree on the production cutbacks necessary to maintain prices, which plummeted to a low of $8 per barrel in 1986 before recovering somewhat. In real terms, oil prices in mid-1987 are about at the 1975 level. Very recent experience shows that markets adjust equally to price rises and falls. In the U. S., 1986 petroleum output fell by 0.8 million barrels per day as marginal stripper wells were closed down while demand increased by half that amount, leading to a sharp upturn in imports.

Thus, history does not suggest that mineral price trends are inevitably downward. In most mineral industries, technological improvements have allowed lower-grade deposits to come into production without pushing up costs, but this balance is complex. It depends on how much ore there is in each cutoff grade (the percent of mineral within rock below which mining is not economically feasible) and on how fast productivity increases and demand for the mineral expands. In the copper industry, for example, switching from underground vein mining to nonselective open pit mining and developing a flotation process and other milling techniques that raised recovery rates from 65 to 95 percent allowed real copper prices to fall from 1900 through the 1930s even though the cutoff ore grade fell from 5 to about 0.7 percent. Thereafter, these new technologies were thoroughly assimilated and depletion of the resource base dominated rising copper prices through the 1970s.[32] This pattern is common to many mineral industries; resource prices seem to follow U-shaped rather than linear paths over the long run,[33] suggesting that the balance could shift from falling to rising prices in the future if demands grew strongly and technical change slackened.

Effects on environmental quality

Fundamental distinctions must be made between the effects of population growth on environmental quality in the richer and poorer countries. In most Third World cities, poverty and rapid urban population growth have resulted in appallingly poor environmental conditions for many or most inhabitants. Because urban land is scarce and expensive, millions of poor households inhabit unauthorized squatter settlements on marginal sites that are often without municipal water and waste disposal services. Such sites are often on inaccessible hillsides, in flood-prone depressions, or beside industrial and other undesirable zones. Poor households must sacrifice housing amentities for basic shelter near urban jobs.[34]

Third World cities have gradually im-

proved and extended their infrastructure, as indicated by statistics on percentages of urban populations with access to such basic services as piped water. Moreover, studies show that individual households typically progess to better housing, employment, and living conditions as they stay in the city longer. However, the rapid pace of urban growth in the Third World creates a constantly expanding fringe population of newly arrived, impoverished migrants and underemployed young urban labor force entrants. Investments in urban infrastructure to keep pace with this expanding population are enormously expensive, and these people have very limited ability to pay for services.

Air and water quality in Third World cities is generally poor, widely violating the minimum health standards of the industrialized countries. Few large-scale and virtually no small-scale industries have effective pollution controls. The vehicle fleet is relatively old, poorly maintained, and also without the emissions controls required in industrial countries. Industrial wastewater and sewage flow untreated into rivers, canals, and bays in many Third World cities. While lack of effective environmental controls is the immediate cause of these conditions, rapid, helter-skelter urban growth that intermixes housing, small-scale and large industries in violation of any rational pattern or plan makes such control doubly difficult.

The absence of standardized monitoring extending back for any considerable period makes it impossible to generalize about long-term trends in urban air and water quality in the Third World, but available data do establish that pollution concentrations are substantially higher than in economically advanced countries and are not currently improving.[35]

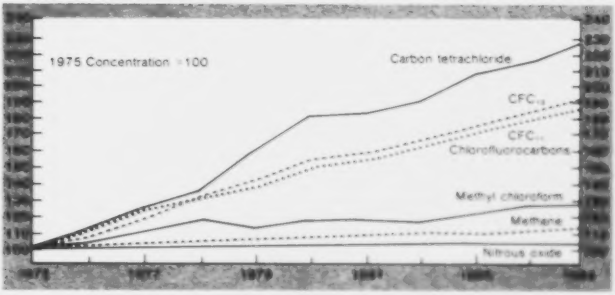
By contrast, most measures of urban environmental quality in economically advanced countries do show gradual improvement. Suspended solids and organic matter in most water bodies have been decreasing. Levels of conventionally measured air pollutants, such as carbon monoxide, sulfur dioxide, and airborne particulates, have also been diminishing. Moreover, despite increasing evidence of damage to forests and lakes from acid deposition, rain's acidity and atmospheric concentrations of sulfates and nitrates have not been increasing during the 1980s.[36]

Acid rain has damaged forests and lakes, as here in Canada, but enforcement of environmental regulations has gradually reduced some air and water pollution in developed countries.

The direct cause of these trends is the enforcement of environmental regulations limiting emissions from motor vehicles, industries, electric utilities, municipalities, and other major pollution sources. Population trends in the industrial countries have had little effect on these indicators of environmental quality.

The importance of environmental regulation is clear in the contrasting trends between these regulated pollutants and other weakly controlled or totally uncontrolled emissions. The most important of these are carbon dioxide and atmospheric trace gases, such as chlorofluorocarbons, nitrous oxides, and methane, that contribute to global greenhouse warming and also reduce the concentration of stratospheric ozone, which

Figure 6. Atmospheric Concentrations of Environmentally Important Trace Gases: 1975-1985



Source: IIED and WRI, *World Resources 1987*, Figure 25.1, p. 334.

is crucial in shielding the earth's surface against ultraviolet radiation. Estimated global emissions of carbon dioxide from the use of fossil fuels and burning of biomass have nearly tripled since 1950. Emissions of the most active chlorofluorocarbons have increased from neglible amounts to almost 700,000 metric tons per year in 1985. Annual emissions have nearly climbed back to the peak levels of the early 1970s, before the use of chlorofluorocarbons in aerosol spray cans was controlled in the U. S., Canada, and Sweden, as other uses have increased, such as in refrigeration, foam-blowing, and solvents.

Figure 6 shows rising trends in atmospheric concentrations of these environmentally important trace gases. The concentration of carbon dioxide (not shown in Figure 6) has already risen about 25 percent over preindustrial levels. Estimates based on samples of air trapped in ice cores suggest that the methane concentration has doubled. Together with rising concentrations of other greenhouse gases, these trends imply that a warming of the earth's surface by 1.5 to 4.5 degrees Centigrade is already inevitable, according to some modeling estimates.[37] This is a significant shift; during the Little Ice Age of the 14th and 15th centuries in Europe, mean temperatures were only 1 Centigrade degree lower than today's. A global warming of 1.5 to 4.5 degrees would lead to a sea-level rise of 20 to 140 centimeters and reduce rainfall and thus crop yields, among other effects.

In sum, population growth rates are not the dominant influence on environmental quality, although very rapid urbanization in the Third World is undoubtedly a significant factor. The effectiveness of environmental controls and the pace and pattern of industrialization are evidently more critical. The record indicates that emissions and other environmental impacts can be controlled within manageable cost levels, provided that legal, regulatory, and incentive programs work.

Consequences of Future Population Growth

The rate at which population growth will subside over the next century in the developing countries is highly speculative and, consequently, so is the ultimate size of the human population. The current United Nations medium estimate of 10.2 billion could easily be off by several billion. In relative terms, even future population growth rates or declines in the economically advanced countries are uncertain.

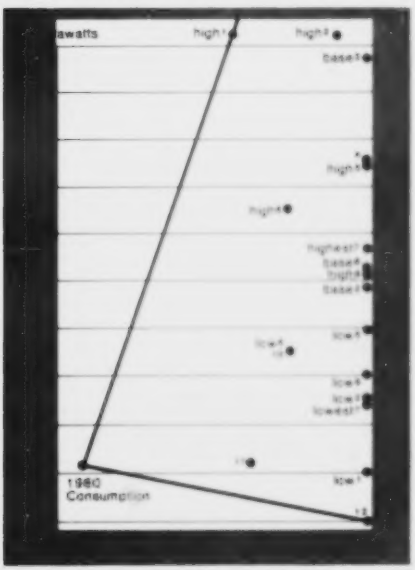
Energy consumption

The same uncertainty pervades long-term projections of future demands for resources, of which energy resources are by far the most critical. Until the oil "shocks" of the 1970s, energy demands were widely thought to be related straightforwardly to growth in population and per capita income. The market adjustments to higher prices that brought energy demands in the industrial countries to a virtual standstill surprised even some energy analysts. Demand forecasts over the past decade have been consistently excessive, and resulted in considerable excess capacity in energy industries.

The longer-term future is even more clouded. Figure 7 presents 19 recent projections of total world primary energy consumption in the period to 2050. They reflect varying "high" and "low" estimates of future population and economic growth and sharply differing assumptions about the extent of future energy conservation. When projected over a half century and more into the future, their implications are profoundly different.

The high estimates range up to more than five times the estimated 10.3 terawatts of energy consumed worldwide in 1980. This implies a tremendous expansion in supplies. The increase in fossil fuel use (assuming that new reserves would be discovered and developed) would mean bringing a new Alaskan oil pipeline into operation every two or three years, while the growth in nuclear generating capacity would necessitate commissioning new one-gigawatt nuclear power plants every two or three days. If these projections should prove to be accurate, concentrations of greenhouse

Figure 7. Recent Long-Term Projections of World Primary Energy Consumption to 2050



Source: WRI and IIED, *World Resources 1986* (New York: Basic Books, 1986) Figure 7.7, p. 115.

Note: The 19 projections appear in the 12 studies listed below. Several represent a range of projections ("high," "base," and "low," for example) produced by varying assumptions used in the same study.

[1] W.D. Nordhaus and G. Yohe, "Future Paths of Energy and Carbon Dioxide Emissions," *Changing Climate* (Washington, D.C.: National Academy of Sciences, 1983).

[2] J.S. Edmonds et al., *An Analysis of Possible Future Atmospheric Retention of Fossil Fuel CO_2* (Washington, D.C.: Department of Energy, 1984).

[3] J. Edmonds and J. Reilly, "Global Energy and CO_2 to the Year 2050," *Energy Journal*, Vol. 4, No. 3 (1983) pp. 21-47.

[4] V.A. Legazov, I.I. Kuzmin, et al., "The Influence of Energetics on Climate," *Fizika Atmosphery i Okeana*, Vol. 11 (USSR Academy of Sciences, 1984) pp. 1089-1103.

[5] D.B. Reister, *An Assessment of the Contribution of Gas to the Global Emissions of Carbon Dioxide* (Chicago: Gas Research Institute, 1984).

[6] International Institute of Applied Systems Analysis (IIASA), *Energy in a Finite World—A Global Systems Analysis* (Cambridge, Mass.: Ballinger, 1981).

[7] D.J. Rose, M.M. Miller, et al., *Global Energy Futures and CO_2—Induced Climate Change* (Cambridge, Mass.: MIT Energy Laboratory, 1983).

[8] S. Seidel and D. Keyes, *Can We Delay a Greenhouse Warming?* (Washington, D.C.: Environmental Protection Agency, 1983).

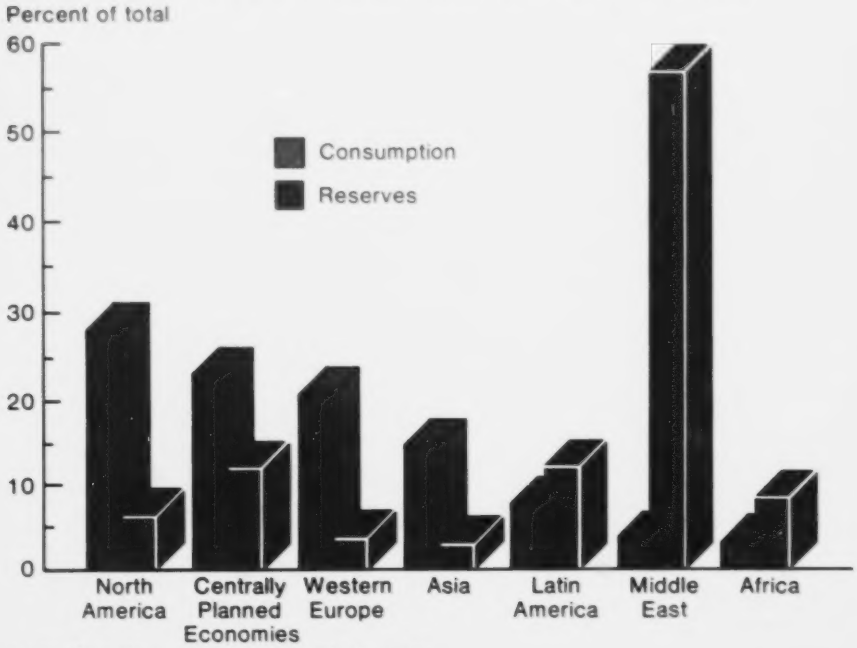
[9] World Energy Conference, *Energy 2000-2020: World Prospects and Regional Stresses* (London: Graham and Trotman, 1983).

[10] H.H. Rogner (ed.), *IIASA '83 Scenario of Energy Development: Summary* (Laxenburg, Austria: IIASA, 1983).

[11] J. Goldemberg et al., "An End-Use Oriented Global Energy Strategy," *Annual Review of Energy*, Vol. 10 (1985) p. 649.

[12] A.B. Lovins, L.H. Lovins et al., *Least Cost Energy: Solving the CO_2 Problem* (Andover, Mass.: Brick House, 1981).

Figure 8. Regional Oil Consumption and Reserves: 1985



Source: Flavin, Hayes, and Mackenzie, *The Oil Rollercoaster*.

gases and global temperatures would rise sharply and up to 4 million kilograms of plutonium would be recovered from spent nuclear reactor fuel each year and circulated in global commerce, greatly increasing the threat of nuclear weapons proliferation. (Only 5 to 10 kilograms of plutonium are required to make a nuclear weapon.)

The low estimates imply a tremendous effort to implement all feasible energy conservation strategies, such that per capita energy use in the industrial countries would fall by almost half from the 1980 level. All buildings would have to incorporate thorough insulation and energy-saving appliances; the entire vehicle fleet would have to be replaced by the most fuel-efficient vehicles now available; all industries would have to install highly energy-efficient motors, furnaces, and other equipment. Between these extremes there obviously lies a wide range of feasible possibilities.

The very recent discoveries of new materials that become superconductors at much higher temperatures than had been thought possible dramatically underscore technological uncertainties. Such superconductors may allow economical long-distance electricity transmission with minimal resistance loss, large-scale energy storage, much more efficient engines, and other developments that will greatly increase the productivity of primary energy sources. Physicists see these breakthroughs as having the same potential impact as the invention of the transistor. Yet, they have not so far been factored into any projections of future energy consumption.

Long-run oil supplies are also highly

uncertain. Although the United States and some other regions have been thoroughly investigated, there remains much to be explored in strata below 10,000 to 15,000 feet, in offshore fields, and in some developing countries. Natural gas deposits have been less thoroughly investigated than oilfields. However, the greatest long-run uncertainties are economic and technological, rather than geologic. Huge known deposits of tar sands, oil shale, heavy oil, coal, and presently unrecoverable oil in existing fields represent enough potential liquid or gaseous hydrocarbons for hundreds of years of consumption, but with current price ranges and available technologies, recovery is economically and environmentally infeasible. Whether prices and technologies will change enough to bring these potential resources into the reserve base is a major uncertainty.

The relatively short-term supply prospect is clearer. Excluding "unconventional" resources, oil reserves will be under pressure within the next 20 to 40 years, depending on the rates of demand growth and new discoveries. Well before then, the Middle East will likely regain the market power that resulted in the 1970s oil price shocks. Figure 8 depicts regional oil consumption and reserves in 1985. The Middle East's preponderance of reserves is striking. Also, production and exploration costs there are far below costs in other regions. Well within a decade, unless policies are adopted to curtail demand, slack in world oil markets is likely to disappear, opening the way for the resurgence of the OPEC cartel.

What actually happens will depend on market forces, but forces shaped and directed by public policies. Governments act to increase energy supplies (through fiscal incentives and subsidized research) or to decrease them (through environmental and safety regulations, for example). Governments also intervene extensively to influence both the composition and level of energy demand, through taxes, subsidies, regulation, and other means.

Nonfuel minerals

Similar uncertainties affect projections of the future demand for nonfuel minerals. As Table 8 shows, for example, even projections made in 1975 and 1978 of the U. S. demand for metals in 1985 were much higher than the actual demand in 1985. This was largely because of significant structural changes in mineral-based industries. Since about 1960 in the United States and other industrialized countries, consumption of most basic materials has fallen rapidly relative to GNP and has remained constant or declined in per capita terms. Figures 9 and 10 (pages 32 and 33) show these trends in the United States for major materials and minor metals. Improved efficiency in using materials, use of cheaper materials or those with more desirable characteristics, saturated traditional markets, and shifts in consumer demand to less materials-intensive products and services are responsible.

These structural shifts may cause serious errors in long-term projections of mineral demands, such as that given in Table

Table 8. Projections of U.S. Metal Demand in 1985 Versus Actual Demand

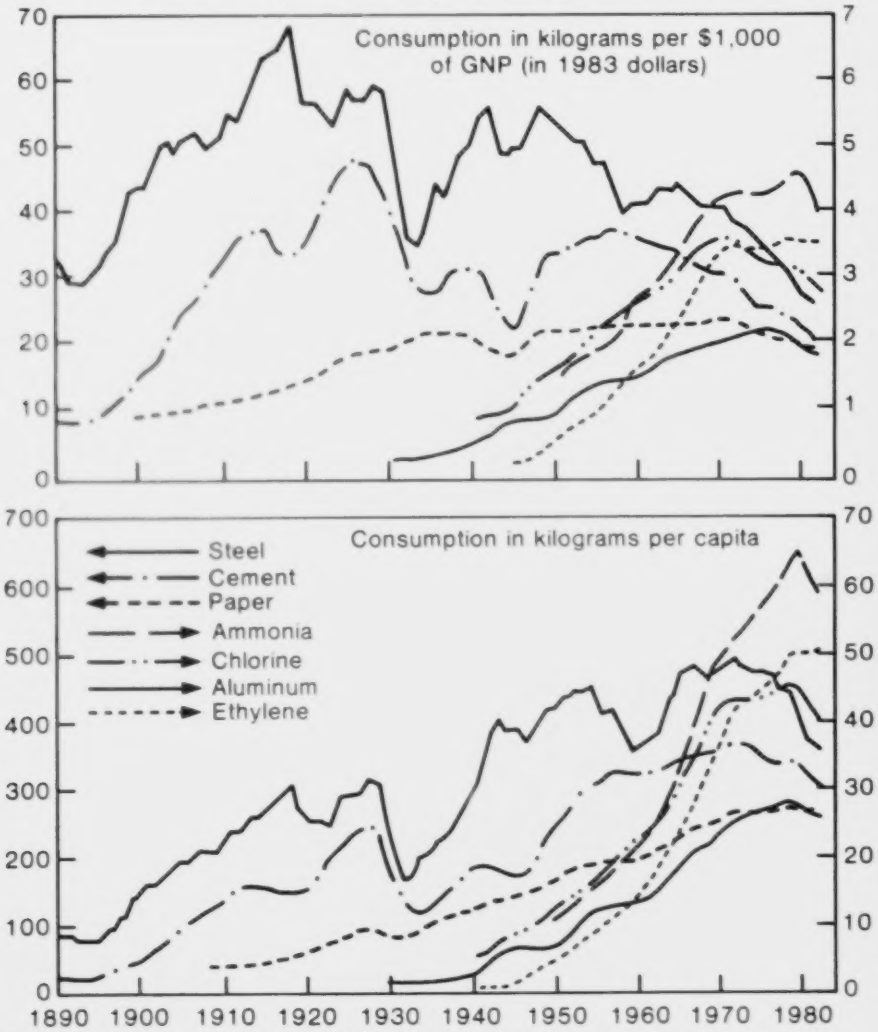
(Ratio of demand in 1985 to average for the period 1971-1975)

Metal	Projected 1975[a]	Projected 1978[b]	Actual 1985
Aluminum	2.12	1.69	1.04
Chromium	1.65	1.08	0.73
Cobalt	1.50	1.48	0.86
Copper	1.66	1.38	1.10
Manganese	1.38	1.13	0.47
Nickel	1.71	1.31	0.79
Steel	1.40	1.24	0.87
Tin	1.11	1.12	0.70
Tungsten	2.01	1.29	1.17
Zinc	1.76	1.38	0.78

Source: Robert H. Williams, Eric D. Larson, and Marc H. Ross, "Materials, Affluence, and Industrial Energy Use," Center for Energy and Environmental Studies, Princeton University, March 1987.

[a]U.S. Department of the Interior, Bureau of Mines, *Mineral Facts and Problems* (Washington, D.C., 1975).
[b]Wilfred Malenbaum, *World Demand for Raw Materials, 1985 and 2000* (New York: McGraw Hill, 1978).

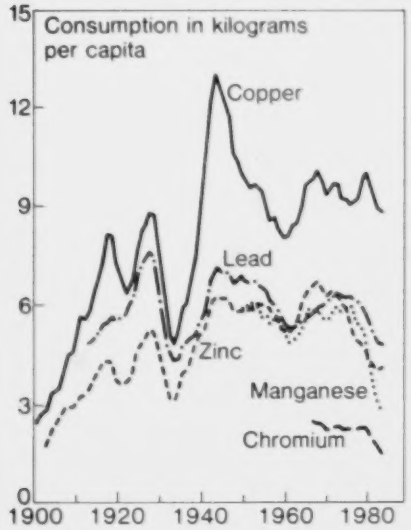
Figure 9. U.S. Consumption of Major Materials: 1890-1985



Source: Robert H. Williams, Eric D. Larson, and Marc H. Ross, "Materials, Affluence, and Industrial Energy Use," Center for Energy and Environmental Studies, Princeton University, March 1987.

9, which assumes, contrary to recent experience, that U. S. mineral demands will grow much faster than population over the 40 years from 1986 through 2025. Global projections are also uncertain. In the early stage of materials' life cycles, market penetration and falling production costs result in rapid growth of demand, or consumption. Stages of slower growth and stagnation follow. Industrializing countries are

Figure 10. U.S. Consumption of Minor Metals: 1900-1985



Source: See Figure 9

in the cycle's early stages, but as per capita incomes rise, they will likely follow the path taken by mature economies.

Scarcity of nonfuel minerals is unlikely to constrain that growth path, although the developing countries will ultimately be the larger source of demand. With the exception of fossil fuels and a few others, the materials most widely used and economically important are available in virtually inexhaustible supplies. Basic life-supporting materials, such as calcium, nitrogen, sodium, and potassium, are available in essentially infinite supply. The possible exceptions are phosphorus, of which there are known high-grade resources to support 500 years of agricultural demand, and a few other trace elements needed in agriculture, such as copper and zinc.[38] Important metals, such as iron, aluminum, and manganese, can be recovered indefinitely from lower-grade ores at manageable cost.

For other materials, substitution possibilities are increasingly ample. Materials' characteristics, such as strength, electrical conductivity, reactivity, and corrosivity, determine current demands. Scientists can now design materials with desirable properties and develop lower-cost subsititutes for more limited materials. For example, modern ceramics (produced from clay, dirt, etc.) can be used advantageously in place of metal alloys for piston caps, cylinder liners, and other critical engine parts, reducing cooling costs, and as high-performance cutting tools.

For this reason, concerns about "critical" materials usually prove to be exaggerated. In 1978 a cobalt mine strike in Zaire, which provides over half the world's supply, set off panic buying that drove the world price from $11 to $120 per kilogram.

Table 9. Projected Growth Rates of U.S. Population, GNP, and Mineral Demands: 1971-2025

(Average annual percent increase)

Indicator and mineral	1971-85	1986-2000	2001-25
Population	0.93	0.74	0.56
GNP	2.91	2.90	2.19
GNP per capita	1.98	2.15	1.63
Aluminum	4.83	3.21	2.81
Chromium	3.01	2.20	1.92
Cobalt	3.40	1.63	2.54
Copper	2.15	1.07	0.99
Iron in ore	1.18	1.55	1.46
Lead	1.78	1.74	1.35
Manganese	2.37	1.83	2.32
Molybdenum	2.20	1.61	1.76
Nickel	3.17	2.32	2.16
Phosphate rock	3.38	1.74	0.82
Potash	2.37	1.33	0.87
Sulfur	1.97	2.29	1.62
Tin	2.16	1.61	1.93
Titanium	2.26	2.17	1.90
Tungsten	3.90	1.63	1.87
Vanadium	2.89	1.95	1.72
Zinc	2.36	1.55	1.66

Source: Ronald G. Ridker and William D. Watson, Jr., *To Choose a Future: Resource and Environmental Problems of the U.S., A Long-Term Global Outlook* (Baltimore: Johns Hopkins Press for Resources for the Future, 1980).

Since then, cobalt use has persisted in catalysts and in superalloys for jet engines, for which few commercial substitutes exist, but overall U.S. consumption has fallen by half. Ceramic (ferrite) magnets have replaced cobalt alloy magnets; manganese has replaced cobalt in paints; and other alloys have replaced cobalt in cutting tools.[39] Even materials derived from limited or geographically concentrated deposits typically have substitutes across most uses, and alternative supply sources, such as recycling, for the rest.

Agricultural resources

Population growth's most direct impact will be not on mineral but on agricultural resources. A world population twice its present size and improving dietary standards in the Third World imply at least a threefold increase in the demand for basic calories, equivalent to an increase to about 10 billion tons of grain each year. To produce this much, all the world's current cropland, including land under permanent crops, would have to yield 7 tons of foodgrain per hectare per year, about what Iowa corn farmers achieve. At present, the average world crop yield per year is 2.3 tons per hectare, and Indian farmers without irrigation manage less than half that much.[40]

Even such crude orders of magnitude raise questions of whether agricultural production can achieve these levels for food crops plus a margin for nonfood crops without severe pressures on other ecosystems. In fact, the world's cropped area can still increase substantially. An FAO assessment of 90 developing countries (excluding China) found that less than half the potential cropped area is now cultivated, and considerable farmland has been idled in the United States and other developed countries. However, the available land (and water) is not in the densely populated countries of China, the Indian subcontinent, Java, Egypt, and the Middle East that account for most of the developing world population, but in North and South America, Oceania, and parts of Africa, where population is relatively sparse.[41] Extending production on open lands implies a vast expansion of world foodgrain exports, which must be offset by exports of manufactures from food-deficit countries. Extending cultivation in the tropics, apart from its impacts on forests and grasslands, depends on solving problems of soil fertility, pests, and diseases.

For all major crops in the developing countries, there are substantial yield reserves, the differences between current averages and those obtainable with known applicable farming methods. Table 10 suggests that cereal yields could triple if input supplies, technical information, farmer incentives, and other preconditions promoted widespread adoption of those techniques. Therefore, expansion of food production to meet the needs of future populations seems within the realm of current possibilities.

The big uncertainty over the long run is the impact genetic engineering will have on agricultural production. Vaccines produced through biotechnology are already available for important livestock diseases, and livestock growth hormones that raise feed efficiency from 25 to 40 percent will shortly be available in commercial quantities. Researchers are altering nitrogen-fixing bacteria to work more effectively and to infect crops other than legumes, which will reduce dependence on chemical fertilizers and raise crop yields on nitrogen-poor tropical soils.

Scientists are also working toward the capacity to alter the genetic makeup of agriculturally important plants by investigating the genetic determinants of key characteristics and by finding means to introduce new genetic material into plant cells. In many respects, progress is outpacing expectations.[42] Ultimately, scientists hope to develop plant varieties with greater photosynthetic efficiency and resistance to such environmental stresses as drought, flooding, salinity, disease, pests, and temperature extremes. The implications for agricultural yields and the use of lands that are now marginal or unavailable for crop production are obviously enormous. According to the National Re-

Table 10. Potential Yields for Cereals in 90 Developing Countries, by Land Class

(Potential yields[a] in 2000 as percent of actual yields in 1974-76)

Cereal	90 developing countries	Land class[b]					
		Ample rainfall	Low rainfall	Naturally flooded	Fully irrigated	Partially irrigated	Problem area
Barley	308.2	339.4	229.0	203.9	278.1	265.0	352.9
Maize	348.6	356.6	157.4	351.3	229.1	306.6	418.0
Rice	256.5	221.6	—	230.2	228.8	257.6	254.8
Wheat	290.7	302.8	377.1	227.3	289.2	227.1	372.0
Other cereals	409.1	511.3	307.7	184.1	224.2	305.6	431.0

Source: Janos P. Hbravosky, "Agriculture: The Land Base," in Repetto, *The Global Possible*, Table 8.9, p. 232.

[a]Potential yields reflect a known technology that is applicable to the area considered.
[b]According to Food and Agriculture Organization, *Agriculture: Toward 2000* project data.

search Council on Agriculture, the tools now being developed for genetic engineering "will likely have an impact on agriculture comparable to that of Mendel's laws of inheritance in the late 1800s."[43] Such scientific changes will likely make long-run forecasts based on existing agronomic technologies highly unreliable.

Adaptations to Population Growth

Innovation is one consistently demonstrated response to scarcity, whether from population growth or other sources. Scientific and technological innovation is rapid in the advanced countries, but change transforms simpler economies as well. Studies of variations in farming practices and land tenure arrangements in Africa demonstrate adaptations to dense population or high demands from nearby market centers.[44]

Table 11 (page 36) shows how farming operations and technology intensify as farming systems progress from forest fallow to multiple cropping. Increasing population pressure induces farmers to use land and available labor more intensively. Fallow periods shorten and more labor hours are used to control weeds and provide supplemental soil nutrients. When farming shifts to annual or multiple cropping, green manures and animal wastes are required to maintain fertility. Since these require substantial additional labor and land inputs, eventually chemical fertilizers become economical.

There is a corresponding evolution in land preparation. When land is abundant, the lighter mid-slope soils tend to be cultivated first with hoes and other simple tools. These soils may be relatively susceptible to erosion, so labor-intensive construction of bunds, ridges, and terraces often evolves as farming pressure increases. Typically, increasing agricultural demands also induce cultivation of fertile bottomlands with heavy soils that are harder to work and often require water control. By this stage, the energy requirements justify keeping draft animals and investments in heavier farm equipment.

As long-term investments in land increase, observers have found that land tenure rights also evolve from general-use rights conferred by community membership toward specific individual property rights. Increasing fixed investments in stump clearance, land leveling, terracing, drainage, and irrigation require assurance that the benefits accrue to the investor and heirs.

Evidence of such agricultural adaptations can be found in Africa and elsewhere in the Third World, paralleling the earlier agricultural history of Europe. Population growth is one stimulus to change, but it is not clear that such farmer-generated innovations can raise

Table 11. Operations and Technology Used in Tropical African Farming Systems

Operations	Forest fallow	Brush fallow	Short fallow
Land clearance	Fire	Fire	None
Land preparation	No land preparation. Sticks used to plant roots and sow seeds	Land is loosened with hoes and sticks	Plow used to to prepare land
Manure use	— Ash — Household refuse for garden plots	Ash, leaves, other vegetable matter and turf from surrounding bushland	— Animal and human waste — Green manuring — Composts — Silt from canals
Weeding	Minimal	Required as fallow period shortens	Required during growing season
Use of animals in farming	None	Animal-drawn plows appear as fallow period shortens	Plowing, transport, interculture
Seasonality of labor demand	None	None	Land preparation, weeding, harvesting
Fodder supply	None	Emergence of grazing land	Abundant free grazing land

Source: Prabhu Pingali and Hans P. Binswanger, "Population Density and Agricultural Intensification: A Study of the Evolution of Technologies in Tropical Agriculture," World Bank, Agriculture and Rural Development Department, Washington, D.C., 1984.

yields at the pace required by exceptionally rapid rates of population growth in sub-Saharan Africa and some other developing countries. Over the long run, European agricultural output grew at 1 to 2 percent per year, whereas Africa's current demographic growth, ranging up to nearly 4 percent a year, requires rates at least twice as high.

Rapid adaptation is neither assured nor automatic. Household and village institutions, such as rules governing inheritance and community membership, mediate responses to population pressures. Government actions that influence the prices farmers receive for their products, the security farmers have in their holdings, the costs and availability of inputs and information, and access to markets also affect agricultural adaptation. In many countries, especially in Africa and Latin America, political instability and policy biases against agriculture have retarded agricultural development.

It is not surprising that the empirical association between measures of population pressure and agricultural intensification is weak. Such pressures can be measured by population density or FAO's more complex measure of "carrying capacity," or changes in those statistics over time. However measured, there is not much correlation between population pressure and indicators of agricultural intensification in countries of sub-Saharan Africa and elsewhere in the Third World.[45]

Similarly, the process of adapting communal tenure rights that are imbedded in political and cultural traditions often proceeds slowly and sporadically. More intensive cultivation on hillsides in semi-arid regions may result in serious land degradation despite the tendency toward greater investment and more secure tenures. When private tenures are established over arable land, problems of controlling access to and use of communal forest and grazing lands usually persist (see box on India, page 18). Adaptation to population growth through local institutional and agronomic change can proceed too slowly to forestall land degradation and falling per capita produc-

Annual cropping	Multiple cropping
None	None
Animal-drawn plows and tractors	Animal-drawn plows and tractors
— Animal and human waste — Composting — Cultivated green manure crops — Chemical fertilizer	— Animal and human waste — Composting — Cultivated green manure crops — Chemical fertilizer
Intensive during growing season	Intensive during growing seasons
Plowing, transport, interculture, post-harvest tasks, irrigation	Plowing, transport, interculture, post-harvest tasks, irrigation
High demand during rainy season and harvest	High demand during land preparation, weeding, harvest, post-harvest
Free grazing during fallow period, crop residues	Intensive fodder management and fodder crop production

tion, as has occurrred in Africa over past decades.

Innovations based on modern science depend both on demand, expressed largely through economic opportunities, and on supply factors, such as the capability to generate, adapt, and apply technical research. The poorest countries, where population growth is generally highest, are at a considerable disadvantage. The scientific and technical innovations developed in advanced countries are sometimes irrelevant or inappropriate to the needs of their markedly different expenditure patterns, production technologies, and input prices. Research and development efforts (and personnel) are attracted to the larger market opportunities of the rich countries.

The availability of scientifically and technically educated specialists in the industrialized world facilitates research and development. Table 12 shows that 90 percent of all scientists and engineers engaged in research and development in 1980 worked in developed countries, and well over 90 percent of research and development dollars are spent there. In sub-Saharan Africa (Africa excluding Arab states), only about 45 scientists and engineers were engaged in research and development for every million people in 1980, compared to nearly 2,900 per million in developed countries as a whole. While many developing countries have raised their capacities for applied research in agriculture, health, and other fields, enormous disparities remain between them and the advanced countries. These differentials are reinforced by the lower average education of the total work force in developing countries, which affects the pace at which innovations are adopted.

The poorest countries have not participated fully in the international diffusion of technology that has brought productivity levels closer together among more advanced economies. Laggards among the now industrialized countries have largely caught up with countries such as the United Kingdom and Australia that had the highest levels of output per worker a century ago. Since 1870 among industrial countries, whether centrally planned or market economies, out-

Table 12. Scientists and Engineers Engaged in Research and Development, by Region: 1980

Region	Estimated number	Estimated number per million population
World total	3,756,100	843
Developed countries	3,359,102	2,875
Developing countries	396,998	121
Africa (excluding Arab states)	16,387	45
Asia (excluding Arab states)	693,659	273
Arab states	33,686	206
North America	674,725	2,679
Latin America and the Caribbean	90,936	251

Source: UNESCO, *1986 Statistical Yearbook* (Paris: 1986) Table 5.4

put per worker has tended to grow fastest in countries where it was initially lowest. In the post-World War II period, newly industrializing countries such as Japan, Korea, Singapore, and Brazil have joined an accelerating process of convergence, as capital and technology have become increasingly mobile internationally.[46]

This long-term process of convergence in productivity and living standards should provide comfort and hope to developing nations. However, the poorest countries have not participated in this convergence. Productivity growth for those countries, on average, has been relatively slow, and there is no discernible tendency for those with the lowest per capita output to catch up. One reason may be that low-income, agricultural countries such as Sudan or Bangladesh cannot readily adopt Western advances in capital-intensive and high-tech industries, while countries such as Japan, Brazil, and Singapore with established industrial and scientific bases can. Although international agricultural research efforts, such as those sparked by the International Rice Research Institute in the Philippines and the International Center for the Improvement of Maize and Wheat in Mexico, have done much to raise yields in developing countries, the effects have been felt mainly on more modern irrigated farms using relatively high levels of purchased inputs.

The demographic dualism that the next century holds, with populations holding steady or declining in developed countries and at least doubling in developing countries, may slow down the process of convergence and promote a corresponding economic and environmental dualism. The more dissimilar are the industrial structures of the poor and the advanced countries, their relative factor scarcities, and their endowments of technically trained workers, the more difficult it may be for the poor countries to adapt and use the rich countries' technological advances. Moreover, with stable demands on natural resources and high per capita incomes, the rich countries will find it much easier to maintain environmental quality than poor countries in which rural and urban populations are growing, pressures on natural resources are increasing, and investment funds are stretched to provide employment for increasing labor forces and infrastructure for expanding cities.

Room to Maneuver

The broad trends and tendencies described in this *Bulletin* admit a wide range of possibilities. In every dimension of development, best-performing nations are far above the average.[47] There is ample room for communities and countries facing natural resource pressures to maneuver. Historically, many nations with extremely limited natural resources have built successful economies and even empires on skills in trade and manufacture. Venice, Holland, Portugal, even England overcame severe resource limitations in this way.[48] Japan, Korea, Singapore, and Hong Kong demonstrate that the strategy is still viable. Despite an almost complete absence of natural resources, the Republic of Korea has raised per capita output fivefold over the past 25 years and has become a major industrial exporter.

Similar progress is possible in agriculture, despite resource limitations. China, although having only about 0.1 hectares of already intensively cultivated arable land per capita, has raised net agricultural output since 1978 at an average rate of about 7 percent per year, largely by putting more land under individual household management and improving farmers' incentives.

In sub-Saharan Africa, Malawi's agricultural output has increased by more than 7 percent annually since 1973, although its rural population density of 59 people per square kilometer is the third highest in Africa and the typical land holding is less than 2 hectares. Malawi's President Kamuzu Banda is also Minister of Agriculture and has promoted diversified cash crops, agricultural research and extension for small farmers, output prices that remunerate farmers adequately, and

Wise management of limited resources has dramatically increased agricultural output in Malawi

investments in rural road networks, education, and other infrastucture.[49]

The key is managing available resources wisely. Too often, current practices and policies promote waste and degradation of the resource base, at heavy economic and environmental cost. Successful experiences demonstrate that there is enormous scope for improvement in resource use. Better management can alleviate apparent and threatened resource scarcities by greatly enhancing resource productivity.

Agricultural policies provide good examples. In most developing countries, agricultural prices are kept low to benefit the urban minority, and public investment supports the urban sector. This, along with concentrated landholdings and other factors, discourages more productive use of good agricultural land and impels the rural poor onto more marginal soils. On the other hand, in the United States, Japan, and Europe, agricultural prices are kept high to benefit the rural minority, inducing farmers to use high levels of chemicals, water, and other inputs to produce costly surpluses, while degrading rivers and aquifers.[50]

Such policies retard constructive innovation while adding to environmental pressures. Scientists are developing simple farming systems for tropical areas that preserve soil fertility by reducing erosion and increasing organic nutrient availability. For example, the International Institute of Tropical Agriculture has developed a system of alley cropping that raises yields 40 percent by intercropping maize or cassava between rows of severely pruned leguminous trees that provide wind protection, water retention, organic mulch, and residual soil nitrogen.[51] However, most governments heavily subsidize chemical fertilizers, lowering the cost to farmers of compensating for lost soil fertility and discouraging use of organic nutrients. Scientists have also developed integrated pest management programs for rice and other tropical crops that minimize the need for chemical pesticides, but many governments maintain generous pesticide subsidies that reduce farmers' incentives to adopt such programs.[52]

Similar anomalies deter progess in using energy resources more productively. Most developing countries rely heavily on biomass energy, especially fuelwood. Many countries that suffer acute shortages of wood for fuel and other uses have nonetheless kept timber prices far below the cost of replacing the wood harvest with forestry plantations, and have deterred replanting even further by not establishing and enforcing clear property rights to standing timber. When China reversed these policies by letting households and cooperatives establish plantations on uncultivated land and sell the harvest at prices negotiated with buyers, the results were impressive. Since 1977 more than 50 million hectares of new plantations have been established, an area half as large as all China's cropland, and wood supplies have increased correspondingly.

In the industrial countries, as indicated by the divergent projections shown in Figure 7 (page 29), there are enormous unrealized opportunities for energy conser-

Tree farming in Costa Rica. Policies to produce wood more efficiently could overcome acute shortages in the many developing countries that rely heavily on fuelwood for energy.

vation through improved energy efficiency. Some arise from the application of semiconductors, superconductors, and other sophisticated technology. Others can be realized through such simple investments as improved insulation and installation of more efficient lighting and motors. Such investments often pay for themselves several times over the life of the installation in reduced energy costs.

The potential energy savings would substantially reduce dependence on energy imports, emissions of greenhouse gases, acid deposition, and other energy-related environmental pressures without sacrificing economic welfare. Yet, government policies in most industrial countries still favor increased energy supply over energy savings. Energy-supply industries are subsidized through a variety of fiscal measures. Prices to energy users are held beneath the true marginal supply costs through rate regulations, and various institutional arrangements deter energy conservation.[53]

Similar opportunities abound to manage other resources more efficiently. Water, consumed mainly in agriculture, is increasingly scarce in many semi-arid areas. In the western United States, for example, virtually all river water has been appropriated and deficits are being met by depleting underground aquifers. Yet current institutions and policies prevent water's reallocation from low- to high-value uses and provide few incentives to users to reduce waste.[54] The same situation prevails in water-scarce countries in the developing world.[55]

Tropical forests, the world's richest and least understood ecosystem, are rapidly disappearing not only because of encroachment by rural populations but also because misguided government policies encourage large-scale conversion to ranches and agricultural settlements, many of which represent inappropriate land uses and could not exist without heavy government subsidies. Timber booms in many tropical countries richly endowed with forests, such as Indonesia and the Philippines, have depleted the resource very rapidly and wastefully, because low royalties and taxes sacrificed much of the economic value of rich government-owned tropical hardwood forests to logging concessionaires, creating enormous short-run profits.[56] Typically, shifting cultivators travel the abandoned logging roads, clearing the remaining forest after concessionaires depart.

These examples indicate the scope of potential improvements in natural resource management, and could be greatly extended. However, it should not be forgotten that population growth is also a variable in the resource/population equation. In countries such as China, Cuba, Korea, and Sri Lanka that have led the Third World in the demographic transition to low growth rates, two mutually reinforcing strategies have worked. First, basic health care and family planning services have been widely accessible. In countries where two out of every five children die

before the age of five from easily preventable or curable diseases, there is little reason for families to limit their births, and where contraceptive supplies and information have not been broadly distributed, the majority of women who want to delay or prevent further births are not adequately protected.

Second, broad-based economic and social development has changed the conditions that perpetuate high fertility and mortality. Women, who are the basic health providers and managers of household resources, have been able to participate fully in development. Basic services, such as primary education and access to safe drinking water, are available to virtually all. Development strategies that expand urban and rural employment opportunities as rapidly as possible provide escapes from poverty and reduce the most severe of all wastages of resources—the wastage of human resources.

In sum, there is considerable uncertainty about the future interactions of population, resources, and the environment, but there is room to maneuver. Although population numbers in developing countries will inevitably be much larger when world population finally stabilizes, those numbers could be stopped short of the additional 5 billion currently projected for developing countries by wise, humane development and population policies adopted now. This will help relieve further inevitable pressures on natural resources and the environment. Those pressures can be further reduced by strengthening the management of the natural resource base. There is no reason to conclude that substantial, sustainable improvements in living conditions for all the world's people are beyond reach and no reason to neglect opportunities to promote that goal by adopting policies to bring the two sides of the equation into balance, so that sustainable population numbers will be balanced with sustainable resource supplies and environmental quality.□

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